DEVELOPMENT OF A SUSTAINABLE FRAMEWORK TO MANAGE FLARE GAS IN AN OIL AND GAS ENVIRONMENT: A CASE STUDY OF NIGERIA

EMEKA NNANNA OJIJIAGWO

DOCTOR OF PHILOSOPHY

2017

Development of a Sustainable Framework to Manage Flare Gas in an Oil and Gas Environment: A Case Study of Nigeria

Emeka Nnanna Ojijiagwo

BSc (Hons), MSc.

Faculty of Science and Engineering

University of Wolverhampton

United Kingdom

A thesis submitted in partial fulfilment of the requirement of the University of Wolverhampton for the Degree of Doctor of Philosophy

July 2017

DECLARATION

I certify that this work has not beenaccepted in substance for any degree, and is not concurrently being submitted for any other degree other than that of Doctor of Philosophy (Ph.D.) being studied at the University of Wolverhampton. I also declare that this work is the result of my investigations, except where otherwise identified by references and that I have not plagiarised the works of others.

…………………………… …………………………

Emeka Nnanna Ojijiagwo Date

(Student)

DEDICATION

This thesis is dedicated to God Almighty for His guidance and direction from beginning to the end of the Ph.D. research.

ACKNOWLEDGEMENTS

I would like to thank God Almighty for His infinite grace, love, wisdom, and strength throughout my Ph.D. programme. Without God, this would have been impossible.

I am very grateful to my Director of Studies, Professor Chike F. Oduoza for his constant academic guidance, encouragement, and support. Your understanding and patience were beyond my understanding. I absolutely appreciate.

I am also appreciative of my second supervisor, Dr. Nwabueze Emekwuru for his thoughtful supports and contributions towards the completion of this programme.

To my loving, caring, and ever understanding parents, HRH Sir and Lady S. Ojijiagwo, words cannot express my sincere gratitude for the spiritual, moral, and financial supports that you have always provided for me. To my sister, Chichi Ojijiagwo you have always been special to me, and in the course of these past four years, you have demonstrated more love: you will always have a special space in my life. I am very grateful to all members of my family for their various supports – Ikenna, Gordon, Uchenna, Uloma, Ugochi, Chinonyerem and Charlyn. God will continue to bless you all.

Specially, I want to thank Dr. Emeka H. Amalu for his sincere academic support and kindness.

I am also very grateful to the staff of Okoloma gas plant, Afam power station, and Rivers State independent power station, for their special contributions towards this research. God bless you all.

Finally, special thanks to my friends and colleagues, who have shown love, support, kindness in various ways. Solomon Adjei, Nengi Odimabo, Bryan McCarthy, Chimene Obunwo, Pastor Kehinde Joshua, Emeka Ogbuehi, Deinsam Ogan, Osarumen Ogbomo, Williams Oko, Kachi Okogbue. I really appreciate.

ABSTRACT

Associated natural gas is produced as a by-product from crude oil exploration and production. When perceived as a non-desirable product, it is wasted during gas flaring. Globally, about 100 Billion Cubic Meters (BCM) of gas is flared annually, leading to release of about 300 million tons of carbon dioxide yearly into the environment. Russia and Nigeria flare more than other countries to the tune of 35.5 and 18.27 BCM, respectively. The consequence of gas flaring has continued to pose significant threats to the environment as well as the economy of oil and gas producing countries. Therefore, this research is aimed at developing a sustainable framework that could enable management of flared gas in an oil and gas environment by generating energy and also minimise environmental impact that arises from gas flaring process. Three major research gaps were identified and they include lack of existing gas flare management framework in Nigeria, lack of economic evaluation of gas to wire (GTW) technology for flared gas reduction and, lack of cordial relationship and understanding between oil and gas producing/flaring companies and electricity producing sectors towards gas flare management. A qualitative research strategy was employed – utilising the single case study approach with embedded units of analysis. Three case study companies were used - one oil and gas producing company, and two electricity-generating companies. Data collection involved semi structured interviews, documentation, observation, and review of relevant literature. Data was analysed using QSR Nvivo version 10. A framework for flared gas reduction was developed based on literature review and also from information made available by experts operating in the oil and gas and electricity sectors. The framework shows inputs from various stakeholders, as well as an evaluation of volume of gas produced, utilized and flared. An economic assessment of GTW technology was carried out to determine the cost effectiveness of the framework. Findings from the study showed that GTW is a viable means of management, and could reduce the total volume of flared gas in Nigeria to 7.1%. This reduces environmental, health and safety hazards. It is also economically profitable. A total capital investment of £1.64b is required in the Nigerian context, with a net profit of £1.26b/year, and has a rate of return of investment of 16.3%. This study has demonstrated that GTW is a sustainable technology for reducing flared gas in Nigeria and other countries facing similar challenges as Nigeria; and capable of minimising adverse environmental and health impact associated with gas flaring. Therefore, the developed framework is also recommended for effective management of flared gas in such countries.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BCM	Billion cubic meter
Bn	Billion
CH_4	Methane
CO_2	Carbon dioxide
CS-1	Case study company 1
CS-2	Case study company 2
CS-3	Case study company 3
EOH	Equivalent of operations hours
GT	Gas turbine
GTL	Gas to liquid
GTW	Gas to Wire
IPPs	Independent power plants
KW	Kilowatt
LNG	Liquefied natural gas
MCM	Million cubic meter
MMSCF/D	Million standard cubic feet per day
MW	Megawatt
PHCN	Power Holding Company of Nigeria

CHAPTER ONE – INTRODUCTION TO STUDY

1.1 BACKGROUND OF THE STUDY

In the process of routine operations that are involved in the production of oil and gas, there is a controlled system that involves the burning of associated gas. According to OGP (2000), that process is referred to as gas flaring, and could take place at oil wells, refineries and even in chemical plants. The gas that is flared is purely natural gas made up of hydrocarbons.

Over 100 bn Cubic Meters (m^3) of natural gas is annually flared worldwide (M.E.E., 2012) as clearly shown in Figure 1.1; and evidence goes further to show that gas flaring has actually reduced in some parts of the globe: but it is not totally incorrect to state that in general, gas flaring has not reduced. This is because flaring has severely increased in countries like Russia, Nigeria and other major producers of crude oil over the years (Broere, 2008).

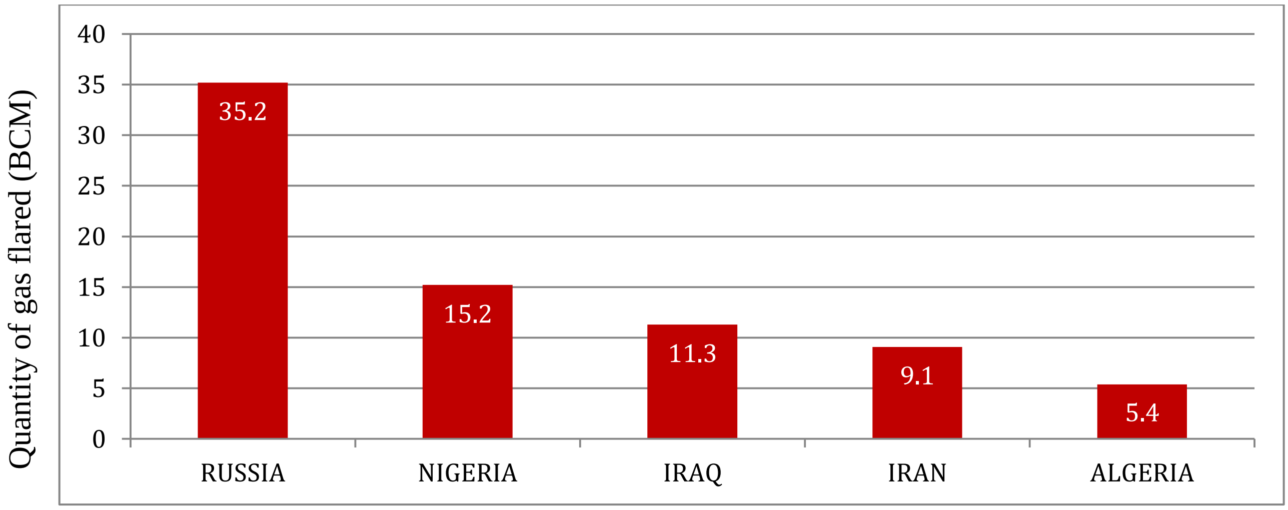

Figure 1. 1: Representation of quantity of gas flared by top five flaring countries (MEE, 2012)

There is need for gas flaring to be checked, minimized or eradicated so that the negative impacts could seize. The environment is polluted by Sulphur oxides and carbon dioxide as a result of gas flaring (Hewitt *et al.*, 1995), leading to the risk of global warming; also, there is the issue of waste of resources. In fact, according to BP (2012), Nigeria has a proven natural gas reserve of about 181 Trillion Cubic Feet and is at a loss of about $2.5bn annually due to gas flaring. There is also a problem of destabilization of the ecology, courtesy of gas flaring.

Previously, several authors (Agboola *et al.*, 2011; Economides *et al.*, 2004; Economides, 2005; Ishisome, 2006; Odumugbo, 2010; Oni and Oyewo, 2011; Sonibare, 2006) have identified and highlighted the problems posed by gas flaring. They have also gone further to identify infrastructure or technology that could be utilized to reduce gas flaring, and hence prevent the negative effects in Nigeria and beyond. However, literature evidence shows that the studies described above were primarily descriptive/explanatory, which basically concentrated on the problems. The research carried out here provides a viable and sustainable process for managing gas flaring, and in so doing, reduces or eliminates the impacts that are associated with flaring gas.

1.2 RESEARCH SCOPE AND MOTIVATION

This study investigates the act of gas flaring in the oil and gas-producing environments with the view to provide a sustainable solution to manage it. It uses data from Nigeria and focuses on the Niger Delta region, which accommodates most of the crude oil and gas resources of the country.

The choice of Nigeria as the focus for study out of other countries that flare gas is purpose-driven. The selection is mostly as a result of two major reasons. Firstly, the occurrence under investigation (gas flaring), poses a great menace to the environment, health of the citizens, as well as the economy of the countries directly involved. Nigeria is one of the countries facing high level of gas flaring and its consequences. It is the second highest gas-flaring nation after Russia (Oni and Oyewo, 2011), and flares about 15.2 BCM of gas; loses about $2.5b to gas flaring; and expels greenhouse gas (GHG) to the environment (see BP, 2012; M.E.E., 2012; Odumugbo, 2010).

The second reason for the choice of Nigeria arises from the fact that Nigeria is affected by low generation and distribution of electricity. According to Ahmed *et al.* (2012), only 40 percent of the Nigerian population has access to electricity, the majority of who are concentrated in urban areas. This signifies that most of the citizens living in rural areas are devoid of electricity in

Nigeria. Nigeria needs 12,000 MWh of electricity on a daily basis, but what is ideally obtainable currently is 3358 MWh, while the installed capacity is 6904.6 MW (Aliyu *et al.*, 2013). This just depicts 36.32% of the electricity need. A very good way to manage the flared gas is using it as fuel for gas turbines to solve Nigeria's electricity generation crisis. Therefore, the choice of Nigeria for this research is vital. This research therefore sees the gas flaring challenge and the quest for its management as a catalyst for the improvement of environment, health and safety, and economy. Also with the electricity generation scenario in the country, any positive plan and action for improvement will bring positive change.

In conclusion, using Nigeria as a case study also stems from accessibility to requisite data for the research. Nigeria has a number of oil and gas operating multi-national and national firms like Shell, Agip, Mobil, just to mention a few, as well as independent bodies that regulate and partner these firms. There are also the national electricity providers, Power Holding Company of Nigeria (PHCN) and some Independent Power Providers, who could serve as means of data collection concerning electricity matters in Nigeria. Concisely, there are several baseline activities in the oil and gas sector and electricity sector of the country; and as a result, this serves as a rich data source for this present research.

This research was established because of the researcher's dissatisfaction with the general gas flaring condition and in particular the Nigerian scenario. The researcher, who hails from the Niger Delta region of Nigeria, is not unaware of the impacts of gas flaring both on the environment and on health and safety. The air in the locality is polluted, residues from gas flaring affect the water sources (ponds, rivers, and rainwater), and the agricultural crops are taunted; yet there is little or no electricity.

The stimulating idea about carrying out this research started during the researcher's Master's Degree Program on Environmental Management, at Coventry University, United Kingdom. In line with this program, one of the modules was "Impacts of Oil and Gas Operations". That module explicitly highlighted the threats posed by gas flaring and gave insight to how technology and technological tools like Gas to Electricity and Liquefied Natural Gas could sustainably manage gas flare. The researcher therefore, is poised to contribute to knowledge, minimize wastage and improve the utilization of gas in the oil and gas sector in Nigeria particularly, and the entire globe in general.

1.3 RESEARCH QUESTIONS

This research seeks to answer a number of questions as follows:

i. What are the reasons for gas flaring in Nigeria, and possible gas flare mitigation measures?
ii. What is the magnitude of the impact of gas flaring with respect to the environment, economy, health and safety of the oil and gas production host communities?
iii. Can flare gas be sustainably converted for energy use through GTW?
iv. How can gas flaring be minimized to fit into electricity production scheme in Nigeria; and what are the cost benefits of flare gas reduction and conversion of gas for electricity production?

1.4 AIM

The aim of this research is to develop a framework that would enable management of flared gas in an oil and gas environment by generating energy from it as well as minimising environmental impact that arises from it.

1.5 OBJECTIVES

The successful achievement of the research aim stated above, will depend a lot on the following objectives:

1. To concisely review literature on gas flaring and some gas flare reduction technologies.
2. To evaluate gas production, utilization and flaring activities in Nigeria.
3. To evaluate the technological implications of gas to electricity.
4. To evaluate the financial analysis of GTW technology.
5. To develop and validate a framework for flared gas management.

Figure 1.2 highlights a typical flaring site, it clearly shows the wastage of gas through burning, and the same picture shows how it affects the environment adversely, particularly the air.

Figure 1. 2: A typical flaring site in the Niger Delta region, Nigeria.

1.6 RESEARCH DESIGN

The design of this thesis as schematically shown in Figure 1.3 consists of three major stages. These are the study, the methodology, and the results and analysis. As part of the study, a thorough literature review was carried out on gas flaring to understand the problem at hand and the literature review proceeded to the expected means of solving the problem – gas to wire, where a thorough study was carried out on gas turbine, which is the main apparatus utilized. From the literature review, the study identified three major gaps in knowledge, which included lack of existing gas flare management framework in Nigeria; lack of economic evaluation of GTW technology for gas flare reduction and; lack of cordial relationship and understanding between oil and gas producing/flaring companies and the electricity-producing sector towards gas flare management.

To solve the problem of gas flaring, the study adopted an interpretivist approach, which involves use of qualitative research method. This study applied the case study research pattern whereby three case companies are used for the study. One case company is chosen from the oil and gas production sector, and two case companies are chosen from the electricity generation sector. These cases guided the identification of the remote causes/reasons for gas flaring in Nigeria, as well as the electricity generation and distribution scenarios in Nigeria. To successfully achieve these, the study applied interviews, documentary analysis, site observation, and literature review as means of data collections.

The data collected are analyzed through content analysis and thematic analysis. From the results of the study, a flared gas reduction framework is developed, which shows that GTW technology viable and economically profitable.

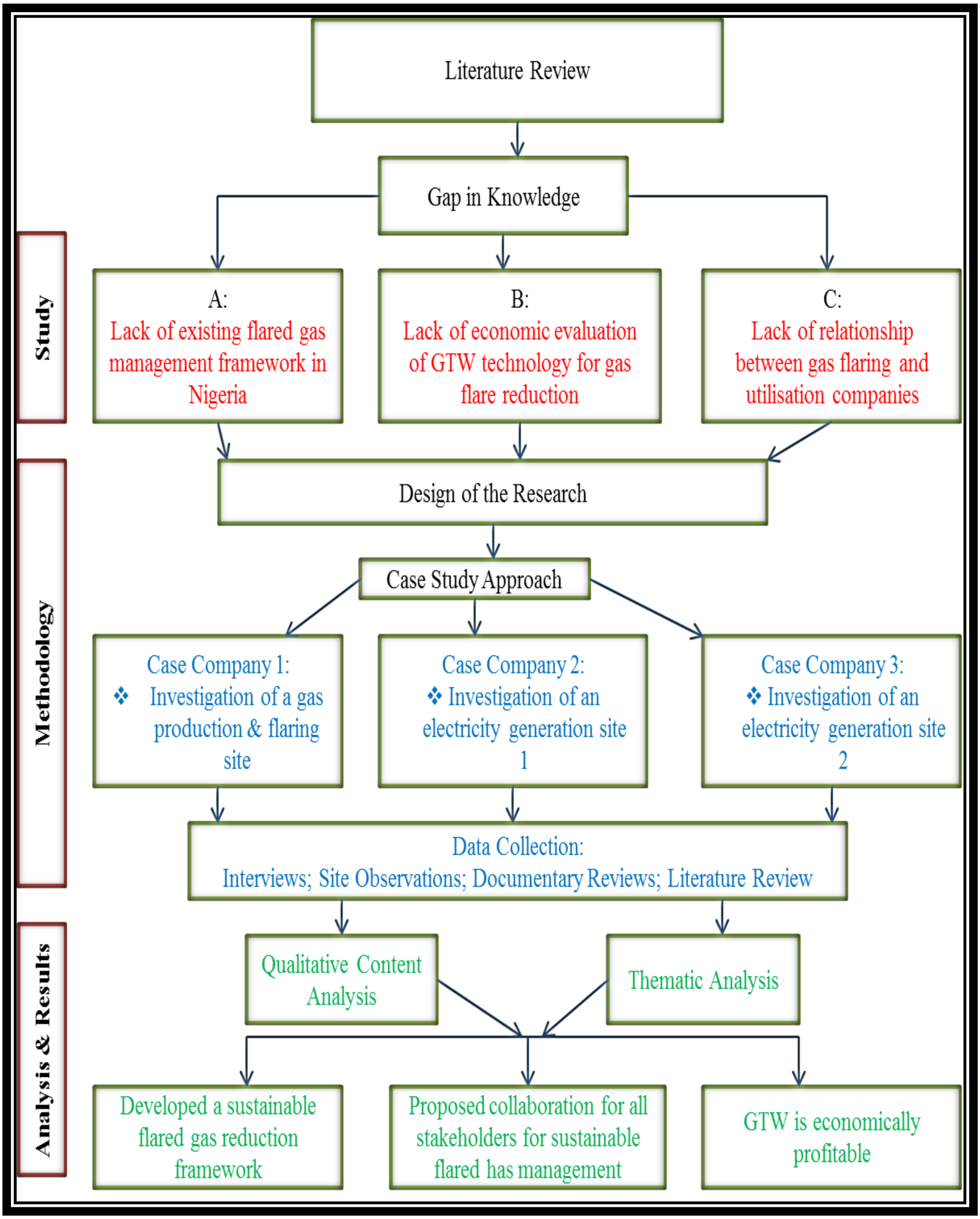

Figure 1. 3: Schematics of Research Design

1.7 CHAPTER SUMMARY

This Chapter covers the background of this study and has provided the research aim and objectives. It also highlighted the motivation that drives the study. Lastly, the Chapter demonstrated the structure of the thesis with the help of a diagram. The next chapter discusses previous studies by other researchers on gas flaring, impacts and management of gas flaring. Additionally, a brief review of Nigeria is discussed.

CHAPTER TWO: REVIEW OF GAS FLARING, ENFORCEMENT AND MONITORING POLICIES, ADVERSE IMPACT AND MANAGEMENT TECHNOLOGIES

2.1 INTRODUCTION

Chapters one has provided data on the estimated volume of globally flared gas. This Chapter reviews studies that have been carried out by different researchers on some major gas producing countries on gas regulations, permission to flare, restriction as well as penalties for flaring. The chapter goes further to discuss the impacts of gas flaring, and ends by discussing technologies that are available for gas utilization. It also provided vital information on gas flaring and on Nigeria as a gas flaring country.

2.2 GAS FLARING AND FLARING IN SOME SELECTED COUNTRIES

According to Agboola *et al.,* (2011), crude oil exploration comes with associated gas that needs to be separated before the oil is refined. During the routine operations that are involved in the production of oil and gas, there is a controlled system whereby the gas or associated gas is burned. That is known as gas flaring; and this process takes place at the extreme of a flare stack (OGP, 2000). It could take place at the oil wells, the refineries or even in the chemical plants. According to Bjorndalen *et al.*, (2005), it is a fact that gas flaring is utilised to dispose the gas that is not wanted or needed at the moment; however, the actual implementation of no-flare design will go a long way in the reduction of emission during production. The awareness created through the environmental impacts associated with gas flaring as well as the Kyoto protocol, the future looks brighter in terms of global gas flaring reduction. Flared gas is made up of several compositions of which, Methane (CH_4) and Ethane have the highest mole fractions. In Table 2.1, the full compositions that make up flared gas are highlighted, while Figure. 2.1 shows the process leading to gas flaring as demonstrated by CCEI (2006). During crude oil exploration, crude oil and associated gas are produced. Crude oil is completely taken to the oil storage after treatment; while the associated gas faces two potential options – systematically gathered for utilization, or wasted through flaring. Regarding flaring, the gas is systematically channeled to the knockout drum from where gas is directed to the flare stack.

Table 2. 1: Composition of Flared (Bahadori, 2014).

Component	Chemical formula	Volume fraction (%)	Weight fraction (%)
Methane	CH_4	81	60
Ethane	C_2H_6	5.5	7.7
Propane	C_3H_8	6.6	13.5
Butane	C_4H_{10}	4.0	10.8
Pentane	C_5H_{12}	1.4	4.8
Nitrogen	N_2	1.0	1.3
Carbon dioxide	CO_2	0.17	0.33

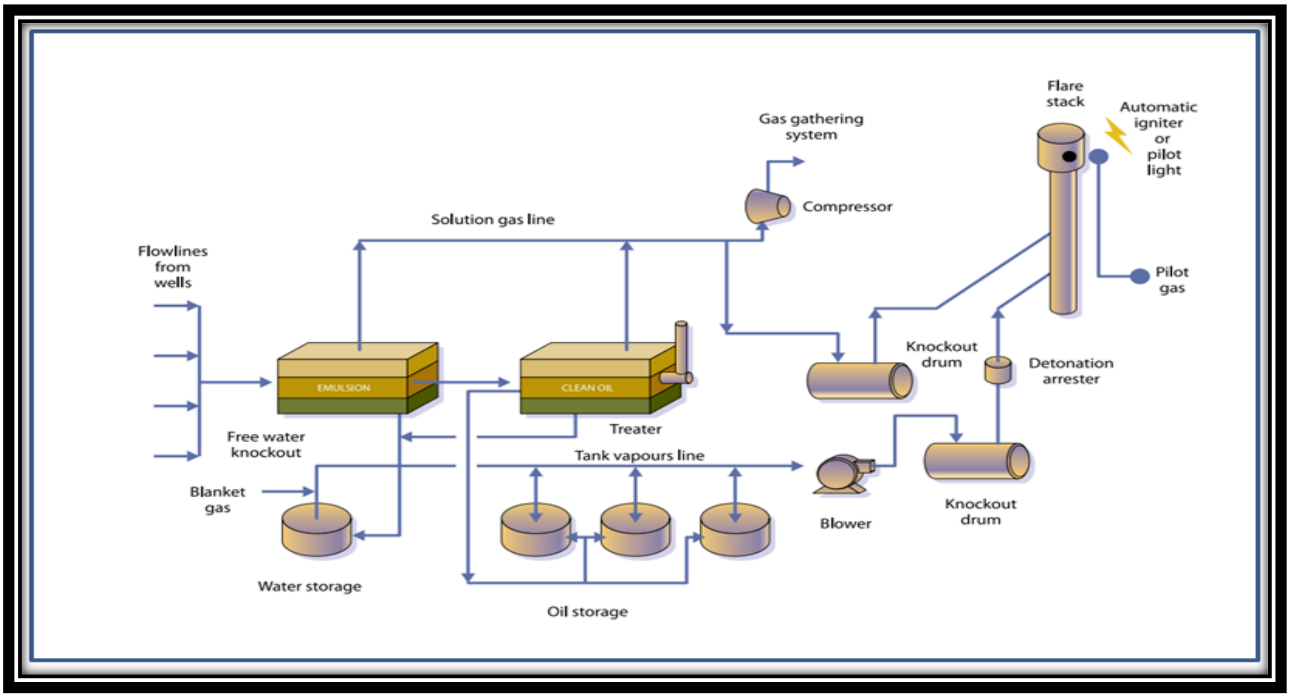

Figure 2. 1: Flow chart for gas production and flaring process (Canadian Centre for Energy Information, 2006)

There could be one or more flares in a typical flare site; however, this depends on the design of the site. Due to some technical or economic reasons like location of natural gas, availability of customers, and government energy policies, a lot of the gas that is flared could not be sold. Therefore, gas may have to be flared as a waste product. However, whatever the reasons may be, there is urgent and severe need for maximal reduction of the flaring of gas for a cleaner environment and minimization of waste which will improve the economy.

According to the World Bank, over 100billion cubic metres of natural gas are flared annually. As a matter of fact, gas flaring has actually reduced in some parts of the globe: but in general, gas flaring has increased. This is because flaring has severely increased in countries like Russia, Nigeria and other major producers of crude oil (Broere, 2008). Figures 2.2 and 2.3 demonstrate the global estimated amount of gas production and consumption from 2001 to 2025 and from 1990 to 2025 respectively (EIA, 2004).

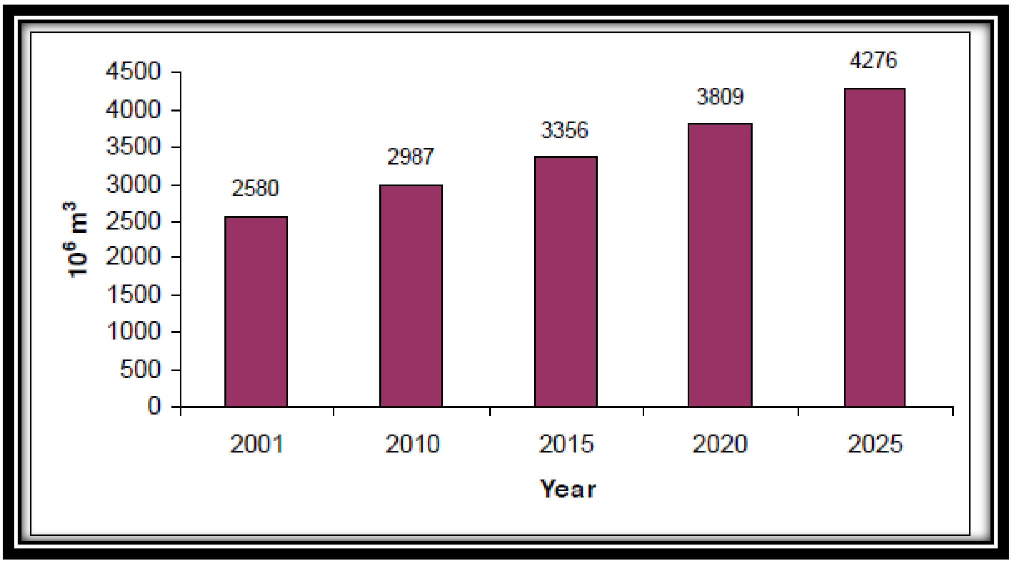

Figure 2. 2: Estimation of World Natural Gas Production from 2001 – 2025 (EIA, 2004)

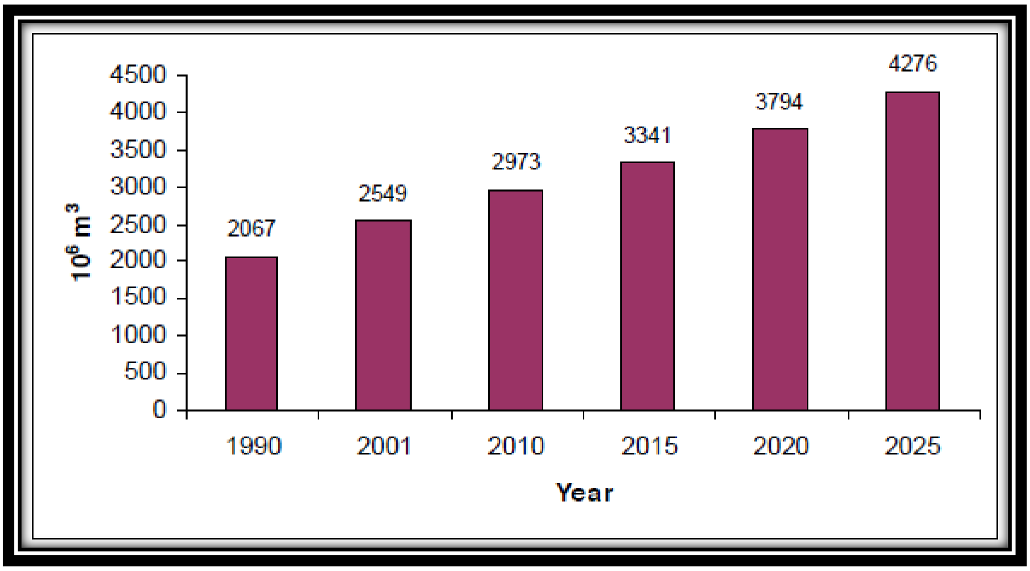

Figure 2. 3: Estimation of World Natural Gas Consumption from 2001 – 2025 (EIA, 2004)

Most of the increase (about 23%) in consumption is expected to emanate from energy consumption and this could be attributed to electricity generation. This is because natural gas is gradually becoming the fastest growing component of world primary energy.

According to OGP (2000), there are various sources that bring about the flaring of gas and some of them may include the following:

- Unburned gas that results from the production process.
- Excessive gas that could not be supplied to commercial customers.
- Vapours that are collected from the top of tanks during the filling process.
- Production shutdown: this involves all the available gas in the facility to be temporarily flared, so that high pressure will be released.
- During process upsets, maintenance and equipment changeover.

However, another source of gas flaring surfaces due to safety precautions in the production sites. This necessitates release of gas in case of high pressures from the valves or other equipment used for operation. But it is very vital to state that the "necessary flaring of gas for safe operations cannot possibly be linked to the major concern about global gas flaring; rather the problem is based or rallied on the systematic severe waste of resource (associated gas) due to lack of gas investments". So for this reason, there is need for urgent remedy.

According EIA (2004), and as seen in Figure 2.4, annual flaring will increase by 60% from 1999 to 2020. This increase is because of the estimated increase on oil crude oil production as clearly specified in Figure 3. It shows that the greatest increase in crude oil production will emanate from the Middle East (46%), seconded by Africa (18%), with the least production coming from North America (3%). Stringent measures therefore are essential for reduction in gas flaring.

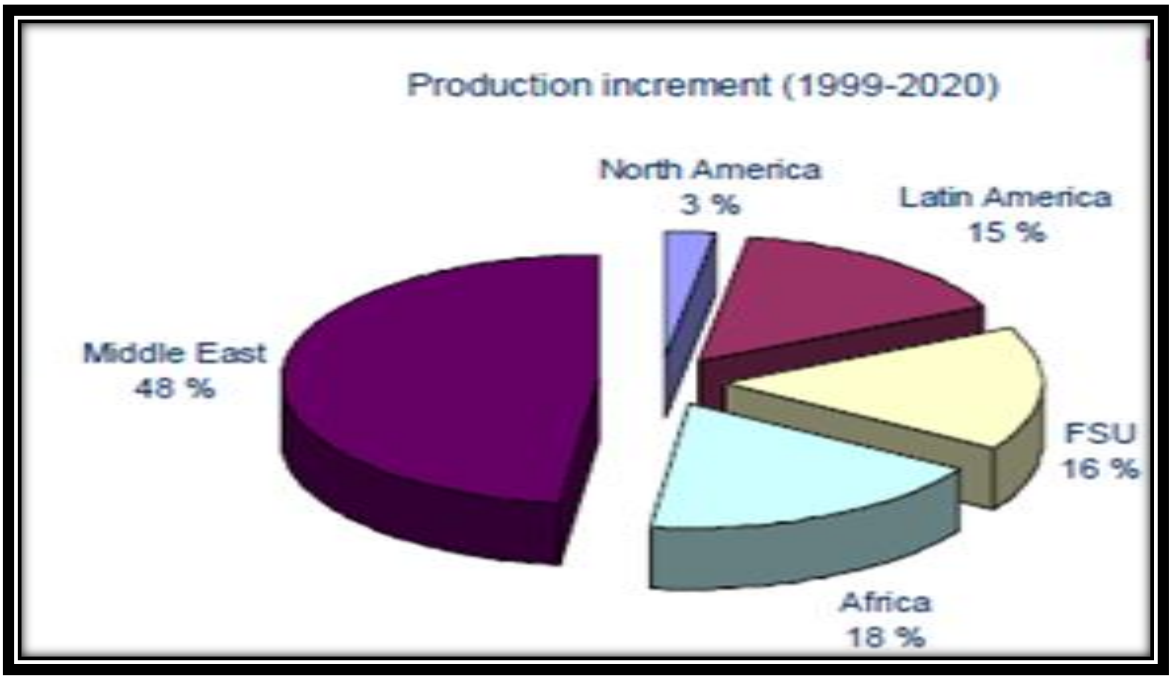

Figure 2. 4: Future Oil Production and Flaring Trends (EIA, 2004 and World Bank's GGFR, 2004)

2.2.1 Gas Flaring In Norway

Norway is a major oil producer, and its oil fields are located offshore in the Norwegian Continental Shelf (NCS). Norway has over 60 oil fields and produces about 2 million barrels of crude oil per day as well as produces about 99.3 billion standard cubic metres of gas per day (Norwegian Petroleum Directorates, 2011). It also serves as the 7th largest exporter of crude oil and boasts as the 2nd largest exporter of gas (Norwegian Petroleum Directorates, 2011). In 2002, oil accounted for about 44 percent of Norwegian exports and 24 percent of government revenue. In 2008, Norway flared just 0.16% of the total annual associated gas from its production of crude oil (CCSI, 2014). The amount of gas flared has varied from year to year, mostly depending on the number of new fields that came into operation. However, flaring volumes as a percentage of oil production has decreased substantially over the last two decades. As a consequence, percentage of flaring volumes has substantially decreased too.

2.2.1.1 Regulation of Gas Flaring In Norway:

The Norwegian Petroleum Directorate (NPD), which is part of the Ministry of Petroleum and Energy (MPE), and the Norwegian Pollution Control Authority (SFT) are the two principal authorities that supervise air emissions and the petroleum activities under the Petroleum and Pollution Act, respectively. NPD is responsible for energy efficiency and safety on installations and for gas flaring and venting operations and enforces legislation concerning the carbon dioxide (CO_2) tax. SFT has overall responsibility for emissions to the sea.

Norway has a laid down principle that is known as the 'Ten Oil Commandments' which are permeated within the Norwegian legislative framework that provides strong policy perspective for legal enforcement (Hunter, 2014). This is known as the Petroleum Activities Act (PAA). The PAA stipulates that resource management of petroleum resources shall be carried out in a long-term perception for the benefit of the Norwegian society as an entity. According to the NPD (2015), Section 4.1 of the Act states that *''petroleum production must be conducted in accordance with prudent production technologies and sound economic principles, to ensure that petroleum resources are not wasted. The production shall take place in accordance with prudent technical and sound economic principles and in such a manner that waste of petroleum or reservoir energy is avoided. The licensee shall carry out continuous evaluation of production strategy and technical solutions and shall take the necessary measures in order to achieve this''.* These acts do not only restrict waste of petroleum resources, but also directs on the best ways to harness them and also stipulates on best utilization measures. Therefore, there is a government act which guides crude oil and gas production and utilisation in Norway: this is a strong reason for very low level of gas flaring in Norway. This could be a possible process that can be adopted by other gas flaring countries for gas flare minimization and utilsation. However, this Act could deter potential investors from coming into Norway, especially for short term investments in the oil and gas sector. This is because the requirements in Norway are huge and also demand a longer completion period.

2.2.1.2 Legal Framework of gas flaring in Norway

The Norwegian Petroleum Directorate (NPD) is administered by the Ministry of Petroleum and Energy, and has the responsibility to advise the Ministry on issues bordering on management of the petroleum resources. It also monitors all data on petroleum activities and the development of different oil and gas fields as well, the responsibility to control flaring and venting activities during crude oil production (CCSI, 2015). This highlights that NDP as a body acknowledges every operations in the oil and gas sector in Norway.

The operators who flare gas during operational phase are responsible for the establishment of internal control system to ensure compliance such as checking sensor calibration every six months. Also operating firms with flaring permit will submit a report showing the volume of gas that is flared daily. On the part of the NPD, it is responsible for the supervision of internal control systems for operators to verify that petroleum activities are done in accordance with the authority's requirements and accepted by company's aims. It also obtains and evaluates the reports of gas flaring that are submitted by the operators concerning the volumes of gas flared within specific periods (basically every six months).

The Petroleum Activities Act 1996 regulates all petroleum activities. This Act regulates exploration licensing, production licensing, cessation of petroleum activities as well as compensation to the community in the event of pollution like oil spillage and gas flaring (NPD, 2015).

2.2.1.3 Environmental And Gas Flaring Policy in Norway:

Since the beginning of oil production in Norway in 1970, the government's policy prohibited gas flaring to avoid wasting valuable energy. The pollution aspect of flaring and venting was introduced later. The Norwegian environmental policy historically has been based on direct regulation of environmentally harmful emissions and discharges (Hunter, 2014). Increasingly, economic instruments such as taxes have been used. The Norwegian authorities consider a close cooperation with the industry essential to achieve the established environmental goals, including reducing flaring and venting volumes, without imposing excessive economic cost burdens on the society.

Operators of the oil and gas industry in Norway are required to carry out an environmental impact assessment (EIA), and this is made public. These operators are not required to carry out any routine flaring for economic reason, but they could secure waivers in some exceptional cases like for safety reasons.

2.2.1.4 Fiscal Framework of gas flaring in Norway

There is a CO_2 Tax which is in connection with petroleum activities since 1991. This tax has increased over the years and as at the year 2013, it is about $0.16 per standard cubic meter of gas flared. Greenhouse Gas Emission Trading Act is also another measure to checkmate gas flaring in Norway. Since Norway is a part of the European Union, it means that Emission Trading Directive with associated decisions applies to Norwegian petroleum activities. Therefore the Greenhouse Gas Emission Trading Act was sanctioned in 2005 and recently amended in 2011. Petroleum activities are currently subject to both CO_2 Tax and mandatory emission allowance. In Norway, there is an Act on CO_2 which provides an additional incentive for reduction of gas flare. Also restrictions for flaring are credited with provision of further incentives for the development of infrastructure or other gas flare reduction technologies.

2.2.2 Gas Flaring In Netherlands

This is oil and gas producing country in Europe, and it has laid down the following policies for the use of associated gas for the operators:

- ✓ Lift, process, and market associated gas, subject to approval of a development plan.
- ✓ Use associated gas in operations or reinject or flare gas, subject to consent and approval.

Until the provisions of the EU Gas Directive were introduced, gas intended for use in the Netherlands must continue to be supplied to Gasunie (National Gas Supplier). The Minister has the sole right for the approval of the sales price of exported gas in Netherlands.

2.2.2.1 Gas Flaring Permission in Netherlands:

Permission to flare gas that exceeds operational requirements and also cannot be marketed is granted by the Oil and Gas Directorate. Associated gas may be used in petroleum operations, reinjected for storage, or commercialized. Gas may be flared and vented for normal operational safety reasons but must otherwise be approved by the Ministry. The Ministry imposes strict restrictions on how flaring and venting take place.

The Convention for the Protection of the Marine Environment of the North-East Atlantic, otherwise known as the OSPAR Commission is a legislative instrument that is responsible for the regulation of international cooperation on environmental protection in the North-Eat Atlantic (OSPAR Commission, n.d). The Netherlands is one of the fifteen countries from the European Union that constitute the Commission. At the international level, the OSPAR Commission is in the process of expanding descriptions of best available techniques (BAT) and best environmental practice (BEP) related to oil and gas condensate flaring from well testing.

2.2.2.2 Restrictions and Penalties for Gas Flaring in Netherlands:

Special emission guidelines exist for onshore and offshore operators. These are included in licenses issued for onshore operations. In the case of offshore operations, there is a voluntary covenant between operators and the State to try to meet the standards established in the guidelines. Failure to achieve this in a fixed period may result in legislative imposition of emission standards. The Oil and Gas Directorate is the Regulating Authority.

2.2.3 Gas Flaring In Qatar

In Qatar, operators in the oil and gas industry could lift, process, and market associated gas jointly with Qatar General Petroleum Corporation (QGPC), the national oil company, subject to a negotiated gas agreement; also they could utilize associated gas in operations or re-inject or flare gas, subject to relevant consent and approval.

Priority is given to gas used to optimize oil production. QGPC is entitled to take, free of charge, associated gas that is not marketed and that exceeds operational requirements at the separation point. The state may require the operator to install and operate gathering and transportation facilities to bring gas ashore (using pipeline for instance), and the operator is reimbursed for all costs (subject to separate agreement).

2.2.3.1 Permission to Flare In Qatar:

Permission to flare gas that cannot be marketed and that exceeds operational requirements is granted by the minister. Flaring must be consistent with good petroleum industry practice.

2.2.3.2 Flaring Restrictions and Penalties:

Ministry of Municipal Affairs and Agriculture's (MMAA) Environmental Protection Management Standards state that flares are regulated at the permitting stage and must be smokeless and efficient so that ambient air quality criteria are not violated. For onshore operations, flares should be of the ground-level type and should be enclosed. All flares (onshore and offshore) should operate free of smoke except in emergency conditions. Except for drilling operations, sour gas should not be burned in flares except in an emergency, and then, for limited periods only. The flaring control in Qatar also stipulates that:

- Emissions during normal operations should be free from visible smoke, and emissions of acid soot should be prevented at all times.
- Emissions of hydrogen sulfide should not exceed 5mg/m^3.
- All emissions should be free from offensive odors.
- Unconfined combustion is prohibited (for example, burn pits, refuse, or waste disposal).

There is also stipulation for periods of smoky, high volume, emergency, and salt gas flaring must be recorded in a logbook, to be submitted to QGPC's Environmental Affairs Department on a monthly basis. And above all, it is worthy to note that regulating agency is the Ministry of Energy and Industry in Qatar.

2.2.4 Gas Flaring In Ecuador

Ecuador permits the operators:

- ✓ To lift, process, and market associated gas, subject to a development agreement negotiated with Petroecuador (the national oil company).
- ✓ To use associated gas in operations or reinject or flare gas, subject to relevant agreement.

2.2.4.1 Flare Permission and Adoption of Flare Gas Reduction in Ecuador:

Flaring is not permitted without authorization; however, the permission to flare gas that cannot be marketed and that exceeds operational requirements is granted by the sub-secretariat for environmental protection (SMA) of the Ministry of Energy and Mines. However, the oil and gas sector in Ecuador does not have a structure that clearly identifies and states the roles and functions of the State. The institutions in this sector include the National Hydrocarbons Directorate which applies the policy and the Ministry of Energy and Mines, which is responsible for defining the policy for the sector (Mayorga-Alba *et al.*, 2008). Furthermore, Mayorga-Alba *et al.* (2008) stated that Ecuador lacks both defined environmental legislation for oil and gas exploration as well as a framework on environmental protection which support a sustainable development of the sector. To a large extent, this challenge has caused social conflicts to evolve in the oil producing communities, and in some cases, has caused severe security treats.

2.2.4.2 Restriction of Flaring and Penalties:

After the establishment of the Global Gas Flaring Reduction (GGFR) by the World Bank in 2002, Ecuador as an oil and gas producing country became a member in 2003. Also in the year 2003, GGFR commissioned a programme which seeks to provide various means for the utilization of flare gas in Ecuador (World Bank 2004). By 2007, the urge to reduce further the act of gas flaring prompted Ecuador to endorse the Global Voluntary Standard, which compels and provides guidelines to the government as well as the oil and gas producing companies how the ways to achieve reduction in both venting and flaring (Mayorga-Alba *et al.*, 2008). Relevant international standards such as those adopted by the Regional Association of Oil and Natural Gas Companies in Latin America and the Caribbean (ARPEL) have been taken into account in setting emission and ambient air quality standards. However, the framework for setting operating standards is provided by Decree No. 2982/1995 of the country of Ecuador. It is understood that additional requirements can be imposed on a case-by-case basis if warranted by the environmental conditions. Therefore, in a situation of noncompliance, financial penalties may be imposed both under the hydrocarbons legislation (the sums involved are insignificant) and environmental legislation. Noncompliance may also constitute grounds for revoking the operator's rights. Above all, the regulatory agency in Ecuador is the Ministry of Energy and Mines, specifically the sub-secretariat for Environmental Protection within the ministry.

2.2.5 Gas Flaring In Russia

The Russian State owns all mineral resources. Licences which are issued jointly by the Ministry of Natural Resources and the regional authorities are needed for extraction of oil, natural gas, and associated gas. The operators are required to:

- ✓ Lift, process, and market associated gas.
- ✓ Use associated gas in operations or reinject or flare gas.

2.2.5.1 Gas Flaring Permission in Russia:

In Russia, gas flaring restrictions vary from region to region as the federal Mineral Resource Act, which sets standard license terms, does not require the condition on associated gas flaring and usage to be included in the oil production license or license agreement. This has led to gas flaring matters to be isolated to the regional authorities. Presently, only a few regions have included special provisions on associated gas flaring and usage in their regional mineral acts. For example, under the mineral acts of Khanty-Mansijsk and Yamalo-Nenetz—two major oil and gas producing regions in West Siberia—the usage rate of associated gas is a mandatory licence condition that the operator and the regional authorities have to agree on before signing the license agreement. Khanty-Mansijsk subsequently went further and set a mandatory 5% cap on gas flaring (95 percent of associated gas has to be used). However, this 5 percent limit might be increased if the operator's feasibility study can prove this threshold is unrealistic. Often oil companies opt not to negotiate for a higher limit since their compliance with the gas flaring condition is unlikely to be scrupulously monitored in this region.

2.2.5.2 Flaring Restrictions/Legislation in Russia:

The Federal laws in Russia do not historically required oil and gas producing organizations to neither minimize gas flaring nor require the utilization of associated petroleum gas (APG).

Despite this, some regions created and adopted their own rules for gas flare reduction, but it has been a slow and irregular process. Russia has two major gas flaring regions – Yamal-Nenetz and Khanty Mansiysk. These two regions have adopted a gas flaring provision, which they made a standard part of their licence to operators. In Khanty Mansiysk for instance, there is an establishment or permission for 5% limit on gas flaring; however, oil and gas operators are permitted to flare beyond such percentage as far they can demonstrate to the regional authorities that gas flaring is more economical that gas utilization. Despite the effort of the regional authorities, it is worthy to note that out of 213 licences given to operators of oil and gas, just 26% applied the rule in 2005 (PFC Energy, 2007).

In Russia, hydrocarbon licences must come with gas utilization requirements; however, these laws are rarely enforced and this gives the oil and gas operators the leverage to fail to comply. Although another major reason for lack of compliance is that the financial fines that are attached to lack of compliance are very meagre – just capped at $1,540 per year.

2.2.5.3 Monitoring and Reporting Of Gas Flaring:

Theoretically, the licensed operators are supervised by both the Ministry of Natural Resources and regional authorities, and either of the two can initiate licence withdrawal in case of noncompliance with a condition stipulated in the licence. But it is worthy to note that neither the regional authorities nor the ministry have ever revoked any licence because of excessive gas flaring (PFC Energy, 2007), even though Russia is rated as the highest gas flaring country worldwide (Rahimpour, 2012): which can be partly blamed on the lack of clearly defined authority (powers) as well as clearly assigned (divided) roles and responsibilities among government supervisory agencies. The lack of standardized reporting, monitoring, and enforcement procedures make the task of ensuring compliance with licence conditions even more difficult. Data on associated gas are reported to several government agencies, including the State Statistical Committee, the Ministry of Taxation, the Ministry of Energy, and the Ministry on Natural Resources, as well as to the committees within the regional governments in charge of natural resources. Since there has been little coordination among these recipients of statistical information, data are not systematically cross-checked or synchronized, and consequently they are to a large degree inconsistent. The comparison of data received and collected by different government agencies reveals that often the volume of flared gas reported by a producer to the

Ministry of Natural Resources exceeds the associated gas production reported by the same producer to the Statistical Committee and the Ministry of Taxation.

The Khanty-Mansijsk government has been working on creating guidelines that, if introduced, will result in stricter requirements on associated gas measuring and reporting, and improved and standardized procedures in monitoring associated gas flaring and usage. Two regulating agencies are responsible for gas flaring regulation in Russia and they are:

- Ministry of Natural Resources
- Regional Authorities (Department and Committees of Local Governments).

2.2.5.4 Enforcement of Anti-Gas Flare Law in Russia

Even though Russia has multiple agencies that enforce utilization of gas, this process has been marred by poor monitoring which has advertently limited the availability of information to the regulators. Also the enforcement tools that currently exist in Russia are not sufficient enough to motivate the utilization of gas. According to PFC Energy (2007), there is neither stringent punishment nor strong incentive that encourages reduction of gas flaring in Russia. However, over the years, the Russian government has indulged in some enforcement improvement steps. In the year 2005, the Ministry of Economic Development and Trade increased the fees for the emission of CH_4, this also included. The implication is that operators, who emit above the required or stated limit will pay 250 Rubles per tonne. Also in 2007, with a prospect to achieve 95% utilization of associated petroleum gas by 2011, the Russian Ministry of Natural Resources proposed a plan with a stringent financial fine of about five-folds of the existing fine.

2.3 OVERVIEW OF NIGERIA AND THE NIGER DELTA

Nigeria is a country located in the Western part of Africa and shares boundaries with the Republic of Benin in the West; Chad and Cameroon in the East; Republic of Niger in the North; and board of Gulf of Guinea in the South and the Atlantic Ocean (Internet World Stats, 2009). The country has an area of 923,768 sq km with an estimated population of over 158.3 million and the official language is English (Trading Economics, 2011). It is also the most populous country in the entire African Continent. Nigeria accounts for 47% of West Africa's population and ranks 8th amongst the top ten countries with the highest population in the world (Internet World Stats, 2010). Figure 2.5 shows a typical map of Nigeria, detailing the 36 States and the federal capital territory, Abuja.

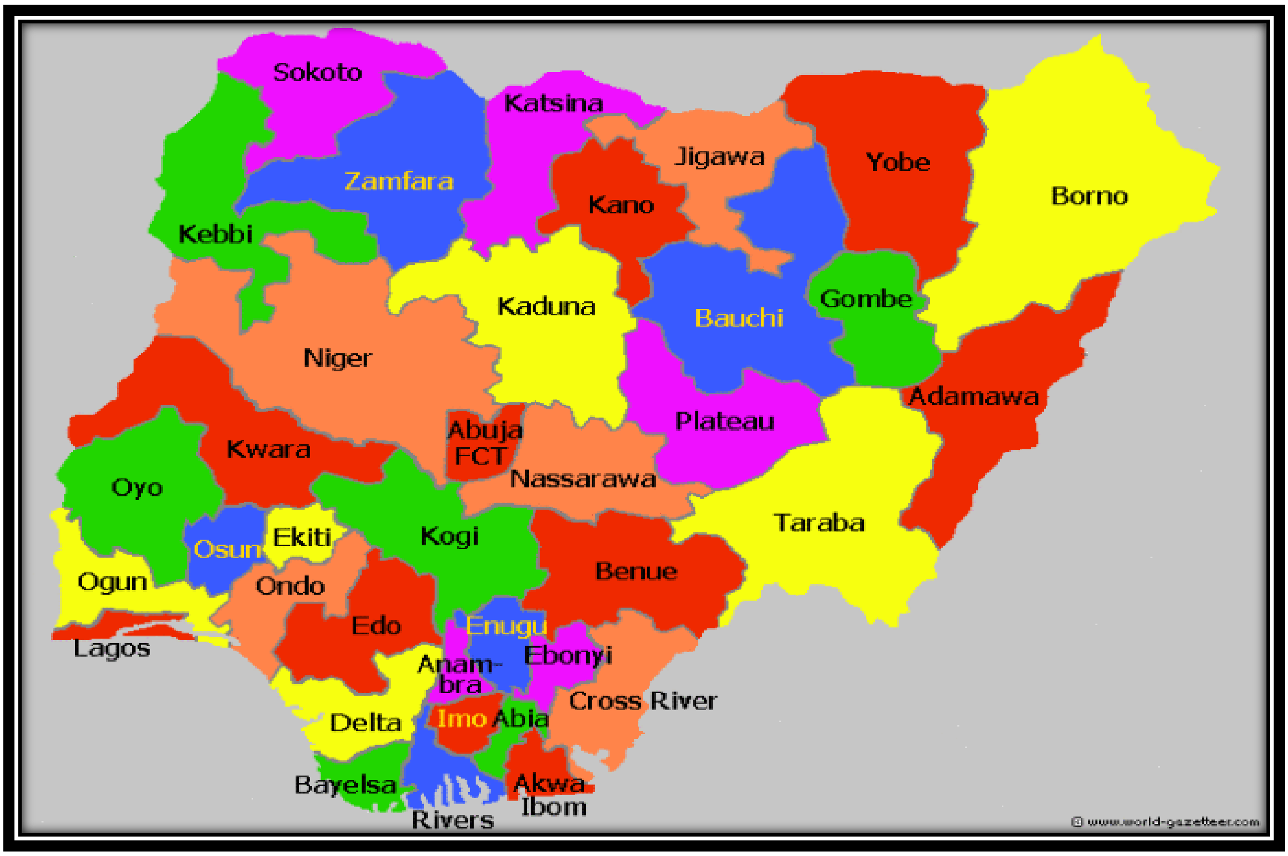

Figure 2.5: Geographic Context of the Study - Nigeria Map (Adapted from Premium Times, 2016).

Nigeria is enormously blessed with abundant human, agricultural, petroleum, gas and other unexploited solid mineral resources (Obadan, 2002). However, due to the political instability experienced since her independence in 1960 from British rule, it has experienced decades of political instability; therefore creating social tension and an unpredictable market for businesses (Onuorah, 2009). It is worthy to mention that the Nigerian economy is profoundly reliant on the oil and gas sector and classed as the fifth largest oil exporter to the United States (Ploch, 2011).

The Niger Delta region of Nigeria literally covers about 36,000 kilometers (14, 000 square miles) of marshland, creeks, tributaries, and lagoons which drain the Niger River into the Atlantic (Ibeanu, 2000). About 12,000 square kilometer of Niger Delta is fragile mangrove forest, and this is arguably the largest mangrove forest in the world. It is also the largest wetland in the world. The biodiversity is very high and the area contains diverse plant and animal species, including many exotic and unique flowers and birds. Implied in this ecology is that the Niger Delta is an easily dis-equilibrated environment. The environment is mostly salt water and associated with shortage of arable land and freshwater. Furthermore, transportation through this ecosystem is very difficult.

Today, crude oil is produced in nine States in Nigeria, namely, Rivers, Bayelsa, Delta, Edo, Imo, Abia, Akwa-Ibom, Cross-River, and Ondo. Due to this fact and other political reason, the present-day Niger Delta is technically made up of these nine States as depicted in Figure 2.6, and covers an area of about 41,000 square miles (106,189.50 km2) and habours Nigeria's proven oil and gas reserves. According to Igwe (2011), 70% of Nigeria's proven gas reserves are situated on land, while the rest 30% are offshore.

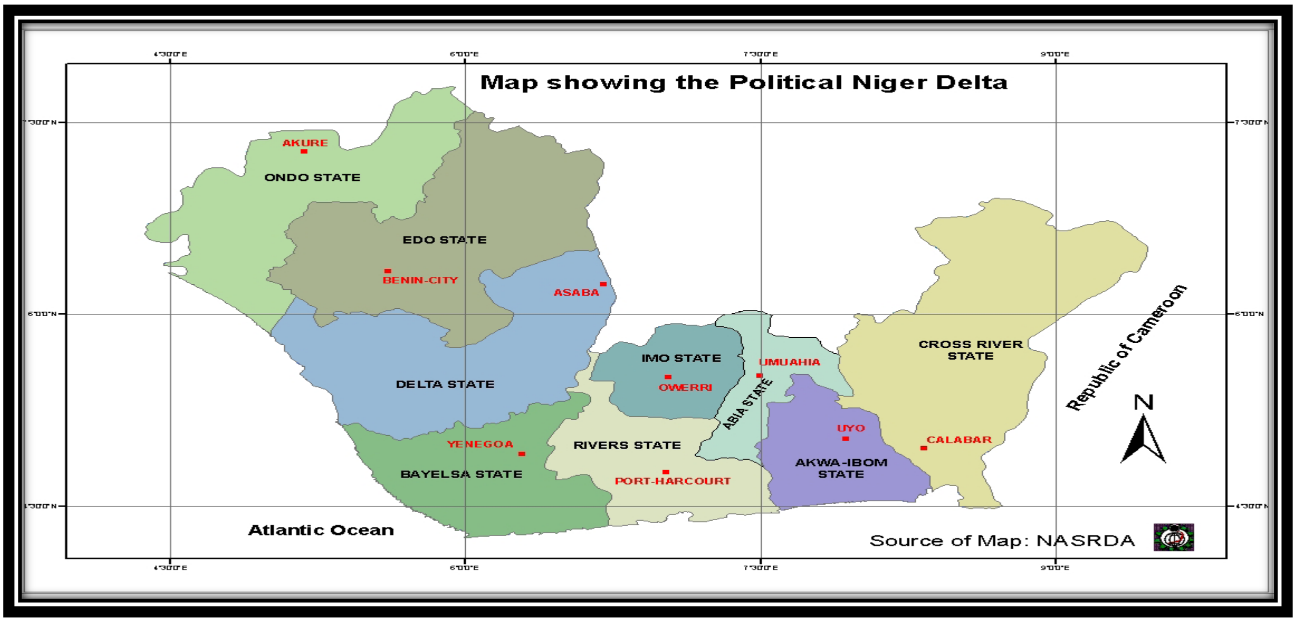

Figure 2. 6: A Typical Map of Niger Delta Region (Ana, 2011).

The Niger Delta, which is the base of Nigeria’s oil resources, has estimated reserves for natural gas to the tune of 5.3 trillion cubic meters (187 trillion cubic feet) (Ahmed Bello and Idris 2012; NLNG, 2011). In terms of gas production, about 33.21 billion cubic meters of gas is produced annually from this region (Giwa, Oluwakayode and Olasunksnmi, 2014). Nigeria has proven oil reserves of an estimated 35 billion barrels and an estimated daily average crude oil production of 2.2 million barrels, therefore the Niger Delta is a key region in Nigeria due to these vital hydrocarbon reserves (Anejionu et al, 2015; NNPC, 2015).

2.4 GAS FLARING IN NIGERIA (NIGER DELTA REGION)

According to Jimoh and Aghalino (2000), gas flaring in Nigeria could be traced to as far as 1906, in Oloibiri, in the present Bayelsa State: and the responsibility rests on Shell-BP, in the effort to discover crude oil in commercial quantity. It is also worth mentioning that the first ever oil field was discovered in the year 1956 and subsequently the first ever crude oil export from Nigeria took place in 1958; and this marked the official gas flaring in Nigeria (Osuoka and Roderick, 2005). And the amount of gas flaring in Nigeria has been on the rise because of the continuous rise in the quantity of crude oil produced: this corresponds with the statement of Oni and Oyewo (2011) which states that Nigeria has become one of the highest gas flaring nations because its oil production has improved in proportion with about 71,000,000 m^3 (2.5billion standard cubic feet).

The crude oil in Nigeria is associated with so much gas (Ikelegbe, 1993), therefore the oil and gas companies in Nigeria prefer to flare the gas that is mixed with the oil (associated gas), so as to maximize crude oil production; and prefer to extract the natural gas directly from its isolated deposit (non-associated gas). Therefore, this is evident to the fact that Nigeria burns a large volume of gas, because the volume of associated gas that is produced and also flared is directly linked to the amount of oil which is produced. Currently Nigeria produces about 2.4 million barrels of crude oil daily (Index mundi, 2015). Above all, as far as oil production is concerned, associated gas is flared (very minimal or nothing at all in developed countries) routinely, however, in the case of Nigeria, it causes a raised eyebrow because so much volume is flared: an estimated $2.5 bn worth of gas is annually flared; which accounts for about 75% of total gas flared in Africa. So much have really been discussed on the impact of oil exploration and production on the environment in Nigeria and they are based on oil spillage as well as the environmental degradation which accompany the act; while in contrast, natural gas and its components have often been neglected, perhaps due to the fact that natural the impacts of gas flaring are not easily visible. This is evident when compared with the effects of crude oil spill, which brings about acute degeneration effects on the environment.

2.4.1 Nigerian Government and Gas Flaring: The Legal Framework

Nigeria's crude oil is linked with plenty of gas, and quite unfortunately, Nigeria is 2nd only to Russia in gas flaring with about 15.2 billion cubic metre of gas, which is flared annually (Bailey *et al.*, 2000 and M.E.E.S., 2012). Ironically, that figure represents about 40% of the gas consumption of Africa in 2001 and about 25% of U.K's natural gas consumption. Gas flaring in Nigeria takes place in the Niger Delta region that is mainly made up of Abia, Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ogun, and Rivers States. The Niger Delta region has a population of about 25 – 30 million people (about 8% of the Nigeria's land mass) and about 20,000 Km^2 (Yakubu, 2008). The flaring of gas in the Niger Delta kicked off with crude oil production in the 1950's. Ever since then, flaring has been on a steady rise, which is a big difference with Western European countries where 99% of the associated gas is either used judiciously or re-injected into the ground. Unfortunately, in Nigeria, despite all the ''regulations'' put in place so many years ago to put gas flaring to a stop, majority of the gas is still flared till now, and this causes local pollution and also contributes so much to climate change, and to a large extent billions of dollars are lost in the process.

In the early 1960s, the Nigerian government recognized gas flaring as a potential problem associated with oil production. Since then, the government has combated it through legislation such as the Petroleum Act of 1969 and the Gas Re-Injection Act. The first time that the Nigerian government tried to prohibit oil companies from flaring gas was in 1969 during the administration of General Yakubu Gowon (military junta). The companies were mandated to put facilities in place for useful utilization of associated gas within five years. Both the government and the oil companies failed. The government has subsequently tried and failed to achieve a zero-flare situation. The last failed mandate for zero-flare was in 31st December 2008; unfortunately, the irony is that gas flaring is just on the rise in the Niger Delta. The Area Manager of ExxonMobil in Nigeria stated that to stop flaring by 2008 would not be feasible due to the security issue in the Niger Delta, the pricing regime for gas and funding of infrastructural development (The Punch, 2007). Nigeria is 'blessed' with both associated and non-associated gases, which are estimated in excess of 160 – 165 trillion cubic feet. Nigeria is ranked the 7th highest producer of gas, accounts for about 13% of the gas flared worldwide and the reserve/production estimate is for about 110 years as specified by specialists.

Shell Petroleum Development Company of Nigeria Limited (SPDC) is the single biggest gas flaring company in the Niger Delta. There are some other major players that include Nigeria

Agip Oil Company (NAOC), ExxonMobil and TotalFinaElf. It is worth noting that the amount of oil produced determines the amount of associated gas produced too; likewise the amount of associated gas produced determines the amount flared – simply put, the amount of gas flared is directly proportional to the associated gas that is produced. It is reported that in 2004, SPDC alone accounted for about 1.1 million bbl/d while ExxonMobil accounted for about 570,000 bbl/d. According to the World Bank, Nigeria flared 75% of all the gas produced. In the Niger Delta, there are more than 100 flare sites, which keep emitting toxic cocktail of chemicals into the atmosphere.

The stoppage of gas flaring in Nigeria has not been successful because of the failure to enforce gas-flaring legislation. The Petroleum Act of 1969 was the first Act that addressed the general potential problem of oil production and its accompanying environmental hazards (Ukala, 2010). This act encouraged oil companies to submit oil-development schemes that specified potential solutions to such environmental hazards. In 1979, the Nigerian government made its first attempt to specifically address the issue of gas flaring by promulgating the Associated Gas Re-Injection Act No. 99. Through this Act, the government mandated that oil companies "re-inject gas for gas utilization. January 1, 1984 was set as the deadline to stop gas flaring; however, an oil company could be exempt from this deadline if they were issued a certificate from the petroleum minister. Major oil companies in Nigeria indicated difficulties in meeting the 1984 deadline, citing lack of resources to construct a gas-injection plant within the timeframe; consequently, the deadline was extended by one year. However, oil companies failed to adhere to the policies stipulated in the 1984 deadline, claiming it was too expensive to re-inject gas (Ishisone, 2006). Consequently, approximately 55% of oil fields were exempted from participating in gas re-injection and an insignificant penalty was imposed on oil fields where gas is flared.

By 2007, the Nigerian department of Petroleum Resources reported that there were about 117 flare sites in the Delta. Gas-flare practices continued to increase dramatically as oil companies deemed it less expensive to pay the minimal fines than to re-inject gas. Consequently, about 75% of gas is flared, whereas approximately only 12% is re-injected. Although legislators promulgated a law to combat gas-flaring, gas flaring remains an issue because of inadequate enforcement due to low penalties imposed for violations and the granting of exemptions to oil companies that flare gas.

2.4.2 Institutional Framework for Gas Flare Management in Nigeria

Nigeria has some vital institutions that are responsible through various means to control and manage the production as well as utilization of crude oil and gas. These have been mentioned and elaborated as follows:

2.4.2.1 Ministry of Petroleum Resources (MPR)

The Ministry of Petroleum Resources in Nigeria is responsible for the creation of all policies that relate to the oil and gas industry. The ministry is under the care of a Minister, and the ministry is also responsible for issuance of regulations and standards for the conducts of other engineering and petroleum procedures. The responsibilities of the MPR are duly carried out through the Department of Petroleum Resources (DPR), which is a body under the Ministry of Petroleum Resources.

2.4.2.2 Nigerian National Petroleum Corporation (NNPC)

This organisation was established from Section 1, Decree No. 33 of 1973 of the Federal Republic of Nigeria. NNPC has two major responsibilities: 1- Inspectoral and commercial responsibility, which allows it to manage and overlook the operations of its subsidiaries within the oil and gas industry, like Nigeria Gas Company (NGC). 2- The NNPC is responsible for the control of the Nigeria's participatory interest in all the joint venture agreements that Nigeria signed with different multi-national corporations in the oil and gas sector.

2.4.2.3 Federal Ministry of Environment (FMENV)

This represents the highest authority in terms of environmental management in Nigeria, and was established in 1999 to replace the Federal Environmental Protection Agency (FEPA). The FMENV was also invested with the authority to be in charge of the Oil and Gas Pollution Control Unit of the DPR. As part of its duty, the FMENV drafted the National Environmental Management Act (NEMACT), which incorporated the policy on gas flaring elimination as well as gas utilization in Nigeria.

2.4.2.4 Niger Delta Development Commission (NDDC)

This is a commission set up by the government in the year 2000 to replace the Oil Mineral Producing Area Development Commission (OMPADEC). One of its major responsibilities is to create a balance between the oil and gas producing communities, the oil and gas producing companies, and the government. Furthermore, the NDDC addresses the environmental challenges that are associated with the activities that are related to engineering and production in Nigeria. It is worthy to note that the NDDC is controlled by a board, which is made up of members from all the 9 States in Nigeria that make up the Niger Delta region.

2.5 RECOMMENDATIONS ON GAS FLARE REGULATION FOR NIGERIA

After reviews on regulations, permissions, and penalties in other oil and gas production and flaring countries, some recommendations are made for Nigeria as stated in Table 2.2. These are currently applied in some countries (see Sections 2.2.1 to 2.2.5) and are creating positive impacts. These recommendations could encourage utilization of gas in Nigeria, particularly when applied strictly and consistently.

Table 2. 2: Regulatory Recommendations for Gas Flare Reduction in Nigeria

S/No	Recommendation	Comments
1	There should be an Act that restricts waste of petroleum resources (gas inclusive), and also directs on the best ways to harness them.	This currently operates in Norway. This Act is responsible for the specification on the best means for gas production and of gas utilization. Norway is a not for good management and utilization of gas, therefore the adoption of this Act in Nigeria will encourage gas flare reduction.
2	Provision of an Act that regulates exploration licensing, production licensing, and cessation of petroleum activities as well as compensation to the community in the event of pollution such as gas flaring should be promulgated.	This exists in Norway as Petroleum Activities Act 1996, and it is responsible for the regulation of all petroleum activities. This could guarantee huge compensation for communities affected by gas flaring and cause the operators to be careful and channel more attention on flare reduction, particularly if the penalty is huge. Fines for defaulting operators should be so exorbitant so as to deter them.
3	Permission that enables operators to flare gas that is of excessive requirements.	This is officially the responsibility of Oil and Gas Directorate in the Netherlands. This could be the responsibility of Ministry of Petroleum Resources (MPR) in Nigeria, because they are responsible for the creation of all policies that relate to the oil and gas industry. This policy will also grant these operators the right to flare (under strict monitoring) gas that cannot be utilized/marketed.
4	Availability of a policy that mandates oil and gas operators to install and operate gas-gathering and transportation facilities	This policy is operational in Qatar, and promotes bringing gas ashore. However, a part of the capital cost would be compensated based on separate agreement by both parties. A good example for compensation could be

	(pipeline).	through tax reduction or tax holidays.
5	Promulgation of an Act that revokes licenses for noncompliance of gas reduction laws and frameworks.	This exists in Ecuador as well as Russia. If applied in Nigeria, it could be a deterrent to oil and gas operators on gas flaring. This will be vital because surely no operator will wish to have its operational licence revoked. Therefore, gas flare reduction process becomes a significant part of their plan. In Russia, two ministries are in charge of the supervision. However, to make this work, particularly in Nigeria, there should be clearly defined authority (powers) as well as clearly assigned (divided) roles and responsibilities among government supervisory agencies. This could be the responsibilities of MPR and Federal Ministry of Environment (FMENV). Furthermore, environmentalists and human right activists should continue in their quest to end this act of gas flaring.

2.6 ENFORCEMENT AND MONITORING OF GAS FLARE SITES IN NIGERIA

Reduction of gas flaring may be difficult to achieve without the political will power in relevant countries in general, and Nigeria in particular. Countries where gas flaring has been reduced to an acceptable or barest minimum like Canada and Norway have three major factors that have been linked together and put in motion. These include legislation, monitoring team and, enforcement team. The combination of these three independent bodies work towards the achievement of a vital aim – gas flare reduction, as has been demonstrated in Figure 2.7.

2.6.1 Legislation

Although Nigeria has different forms and levels of institutional structures used for the course of oil and gas management as stated in section 3.3.2, it is yet to be understood clearly how these structures strictly tackle gas flaring. Therefore, the government through legislation will have to consider some factors like core reasons that lead to continuous gas flaring; how to provide financial support to the oil and gas companies, as well as how to make the environment conducive for the local communities within the oil and gas production and flaring sites. This legislation provides specific and clear directives/guidelines on maximum volume amount of gas that each organization in the oil and gas sector is expected to flare (where necessary); as well as stating means of utilisation, for instance GTW and LNG. These directives will essentially ensure that flaring up to a certain volume of gas becomes an illegal act, thereby declaring the perpetrators as offenders.

The legislation also makes provision for fines and penalties for offenders of these directives. In Nigeria currently, the penalties for this offence is meagre when compared with the volume of flared gas, thereby giving the operators the grounds to continue flaring. However, to make this work, the legislation should carry along heavier and stricter fines and penalties. Providing some incentives such as tax holidays (for few years) as well as tax reduction to the companies in the oil and gas sector will serve as a good indirect financial support and encouragement towards investing on gas flare reduction. In other words, money meant for tax could be channeled towards investment in technologies that reduces gas flaring.

2.6.2 Monitoring

An effective monitoring team is required to effectively enforce the laws that will be enacted by the legislation of the country. Without consistent monitoring, there is a strong likelihood that these legislations for gas flare management may not succeed in the oil and gas sector. This is because Nigeria currently has some institutional frameworks for the management of gas flare; but due to lack of monitoring from the government, these frameworks have proved not to be successful. Therefore, to make the legislation successful, there should be strict monitoring teams who part of their primary duties is to regularly monitor if the companies adhere to the authorized maximum volume of gas flaring.

2.6.3 Enforcement

The duty of the enforcement team is to be unbiased in compelling the oil and gas companies to comply with the directives of the legislation. This team will be entrusted with consistent checks as well as non-discriminatory execution of this duty. If all these are put into effective practice, which will require both the government and the oil and gas stakeholders acting in accordance to their respective requirements, this framework will improve utilisation of gas.

Figure 2.7 shows the roles of legislation, monitoring and enforcement towards the achievement of flare gas utilization. Although each acts independently, it is worth mentioning that they have a common aim, which is gas flare minimization.

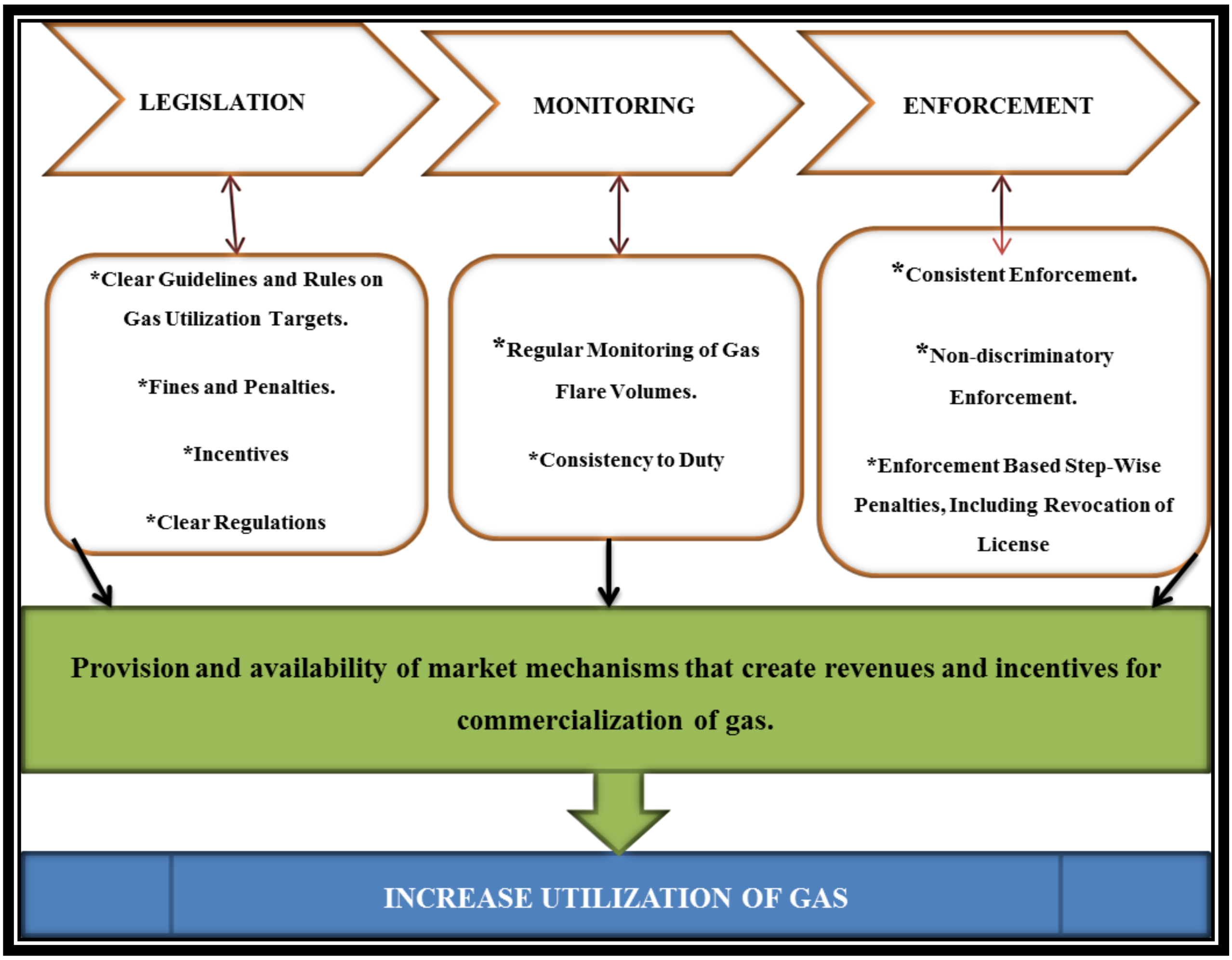

Figure 2. 7: Process Flow for Improved Utilization of Gas

2.7 ADVERSE IMPACT OF GAS FLARING

Gas production carries along routine associated gas flaring (very minimal in developed countries), however, in the case of Nigeria, it causes a raised eyebrow because so much volume is regularly flared.

Though Nigeria has tried to find ways of making the best use of the gas (exporting, re-injecting, use for electric generation or even through any other means), but till date, a huge volume of gas is still flared steadily in Nigeria, particularly in the Niger Delta, which is the major oil centre. The effects that it has on the environment are quite heavy – destruction of fauna and flora, pollution of water bodies which happens through excessive heat and acid rains respectively. There is also the degradation of human health. There has been the negative experience of reduction in the region for flora and fauna because humans as well as fish need them for the livelihood. Gas flaring also brings about waste of natural resources and economic waste. The following sections have extensively discussed these adverse impacts.

2.7.1 Environmental Impact of Gas Flaring

Due to the fact that gas flared from different oil fields has its own characteristics, it is not easy to find a definite measurement of its impact. However, in general, flaring of gas releases hazardous chemicals such as carcinogens and heavy metals, which negatively affect the environment. Anomohanran (2012) suggested that the governments need to be proactive in preventing the release of millions of tons of CO_2 into the atmosphere. In the same vein, Edino *et al.* (2010) also supported the suggestion by opting that gas flaring is a controversial environmental issue because it contributes significantly to greenhouse gas (GHG) emission and can be seen from an economic perspective as a waste of valuable energy resources. These environmental impacts have been highlighted below:

2.7.1.1 Climate Change

Gas flaring contributes to climate change (Orimoogunje et al., 2010), thereby creating severe consequences for the entire globe and Nigeria in particular because of the large volume of gas flaring in Nigeria. Gas flaring is a major source of greenhouse gases (GHG) contributing to global warming which could accelerate the problem of climatic change and harsh living conditions on earth, if not checked (Penner 1999; Meehl 2007). Flaring releases carbon dioxide and methane, the two major greenhouse gases. Of these two, methane is actually more harmful than carbon dioxide, and could also be more prevalent in flares that burn at lower efficiency. However, together and crudely, these gases make up about 80% of global warming (Ajugwo, 2013).

Gas flaring contributes to climate change, which has serious implications for the world (Orimoogunje et al. 2010). Those less efficient flares tend to have more moisture and particles in them that reflect heat and are said to have similar effect on the ozone layer like aerosols do (Orubu et al. 2004; Bassey 2008). Furthermore, Bassey (2008) states that of the greenhouse gases researched so far, the global warming potential of a kilogram of methane is estimated to be twenty-one times that of a kilogram of carbon dioxide when the effects are considered over one hundred years. In the year 2002, according to GGFR (2004), 199 to 262 million tons of CO_2 emissions resulted from gas flaring in the world, i.e. about 3% of the total emission. The amount of greenhouse gas (GHG) emission from gas flaring and venting depend on gas production, its composition, and the flare efficiency. One of the main problems is the unknown efficiency, which depends on several factors such as the composition of the flare stream, gas flow rate and wind velocity. The efficiency determines how much gas will be burnt as CO_2, while the rest will be vented as methane, which has higher greenhouse intensity. Estimations of efficiency range from 20% to 99% and this leads to large uncertainties as to the effects of flaring on the environment (Kostiuk, et al, 2004). The annual gas flaring activities in Nigerian releases about 35 million tons of CO_2 and 12 million tons of CH_4: these are known to possess higher warming potential than CO_2. These gases are known to have increased the average global temperature by about 0.5 degree centigrade in the last 100 years (Penner, 1999). Particularly, there is concern of likely impact of flood, rising sea level and tidal waves in Nigeria. And this fear has demonstrated just a little bit of what it could be, when it perhaps comes in a larger force, as witnessed in the recent flooding that engulfed Nigeria from May to November 2012 as reported by BBC News (2012). For the fact that most of the major and expanding cities in Nigeria are on the coast, with time, Nigeria's low-lying coasts may be threatened by potential sea-level rise. As estimated, about 35 million tons of carbon dioxide and 12 million tons of methane are released into the environment in the Niger Delta; surely this is astronomical and it is a major concern because of its climatic and environmental hazards. So if there should be a case of rise of sea level, there could be inundation along more than 30% of the Nigerian coastline.

2.7.1.2 Acid precipitation

This is acknowledged as a significant effect of gas flaring. When sour gas is burnt, there is the production of Sulphur oxides, which are finally exposed to the atmosphere (Hewitt *et al.,* 1995). When these compounds mix up with water and oxygen, they give out an end product known as ‘’acid rain’’. This causes impacts on agriculture, forest and physical infrastructural contamination, as well as roof erosion (Aghalino, 2009). The primary causes of acid rain are emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO) which combine with atmospheric moisture for the formation of sulfuric acid and nitric acid respectively. According to FOE (2004), acid rains have been linked to gas flaring activities.

The effect of the acid rain can be toxic to the human body; it can also be experienced on the corrugated iron roofs within the flaring area – they just rust quicker now as compared with about 20 – 30 years ago. It is worth noting that the constant input of these acids (no matter how dilute they may be) into the environment can cause increased pH level in the affected areas (Botkin and Keller, 1998). The increased pH level increases the rate of extinction of flora that cannot resist, as well as condemning the water body and making it unfit/unhealthy for drinking (Nwaugo *et al.*, 2005). Flare sites produce some toxic black powders through the flames (soot), which most times deposit/settle on the roofing sheets of nearby villages. This soot is washed into the water aquifers and soils of the inhabitants (Thomas and Allen, 1999).

In Nigeria, the concentration of acid in rain water appears to be higher in the Niger Delta region and decreases further away from the region (Uyigue and Agho, 2007). This is due to the high concentration of crude oil and gas reserves, as well as the high volume of gas flaring in the Niger Delta region, which is more than the occurrence in other regions of Nigeria. The acid rain caused by gas flaring has altered the vegetation of the Niger Delta area. On a casual observation of the flares in the Niger Delta one sees that they are mucky and are evidently burnt at low efficiency. Gas flare sites, which often times are situated close to villages, produce “soot”, which is deposited on building roofs of nearby villages. When it rains, this soot runs off the roofs of building and pollutes the soil as well as water aquifers of the people (Aghalino, 2009).

2.7.1.3 Health and Safety

Hydrocarbon compounds cause some negative changes in hematological parameters. According to Ajugwo (2013), these changes affect blood and blood-forming cells negatively. Properties of gas flaring such as carbon dioxide, nitrogen dioxide, Sulphur dioxide benzene, xylene, toluene and carcinogen compounds (dioxin and benzapyrene) have been linked with leukaemia, chronic bronchitis, asthma as well as infertility. It is nice to note that benzene particularly is known as one of the top 20 toxic chemicals and the exposure of the human body to benzene leads to headache, drowsiness and can lead to death (ATSDR).

Other effects associated with gas flaring at varying levels of 10 -30 years are low birth weight, bone marrow damage, anaemia, decreased immune system and internal bleeding. Particularly, toluene is highly associated with severe nervous system damage. It is also reported that long exposure to moderate or even low amount can cause liver damage, as well as kidney and lungs damage; while long term exposure can even result to memory loss, vision and hearing disabilities and at the extreme death can result. In the Niger Delta, children and women are seen drying cassava and fish through the aid of the heat that comes from gas flares. Actually, it serves the locals that purpose but the irony is that as much as the goods are dried, they acquire some by-products of gas flaring like toluene, benzene etc, and these components are toxic to the body.

Furthermore, the US Environmental Protection Agency (EPA) stated that exposure to benzene causes acute leukemia and a variety of other blood related disorders in humans. World Bank Information on the adverse effects of particulate matter, suggests that gas flaring from Bayelsa State (in the Niger Delta Region of Nigeria) alone, would likely cause on a yearly basis, 49 premature deaths, 4960 respiratory illness among children and 120 asthma attacks (Collins and Oshodi, 2010). In a sour gas flare many reduced sulphur species are formed. Several including hydrogen sulphide and carbon disulphide are potent toxic chemicals. Exposure to H_2S at concentrations below the level it can be smelled is associated with spontaneous abortion. The most common cause of Thyroid cancers is radioactivity. Thyroid cancers have an elevated median rate ratio in those geographic areas with extensive flaring operations. Furthermore, apart from release of greenhouse gases into the atmosphere, gas flaring is responsible for releasing about 45.8 billion kilowatts of heat into the atmosphere in Niger Delta on a daily basis (Ismail and Umukoro, 2012). Therefore, it could be argued that gas flaring raises temperatures and renders large areas uninhabitable.

Gas flaring really goes together with noise, and at times with vibration. It can create so much noise and vibration to people who live at about 6 kilometres radius from it; this affects the way they talk (they tend to shout) and hear (they have hearing problem). In fact, people who visit the Niger Delta at one point or the other complain that the inhabitants tend to talk at high tones (Bailey *et al.*, 2000). These could be traced to noise and vibration from gas flaring, therefore, a source for health and safety concern.

2.7.2 Economic Impact of Gas Flaring

Gas flaring is a form of waste of natural resource and some economic impacts have been stated below:

2.7.2.1 Reduction in Agricultural Output

Soil Infertility is a huge problem that is associated with gas flaring in the Niger Delta. Soil acidification occurs through the deposits of acids on the soil, thereby reducing the PH of the soil surface. This reduces the activities of those microorganisms that sensitive to low pH and decreases the decomposition of plant residue and nutrients. Soil acidification also reduces plant intake of molybdate. The end product/point is that acidification of soil brings about poor farm harvests and in extreme cases brings famine. This subsequently leads to high cost of food items in the local and or national levels. It also affects the livelihood of the local farmers. Gas flaring, in Nigeria for instance, renders the Niger Delta extremely vulnerable to the impacts of climate change. The International Institute for Applied Systems Analysis, Food and Sustainability Agriculture (2008), projects that there will be a loss of 50% ability to produce cereal by the year 2020 and this could rise to about 80% by the year 2050. These acids also get in contact with the water bodies and contaminate them, which makes the water bodies unfit for the fish. This also turns out to affect the economy of the fishermen as well as that of the inhabitant: as far as there is lesser fish available, the price will tend to inflate.

Study by Augustine and Sanford (1976) in Nigeria showed that gas flare could have an effect beyond a distance greater than 110 m from the stacks, except in the case of suppression of the flowering of short-day plants; however, it also states that more/further studies were required to determine the effects of the flares on the yield of crop plants grown in the area. Although it is also worth to mention that soils of the study area are fast losing their fertility and capacity for sustainable agriculture due to the acidification of the soils by the various pollutants associated with gas flaring in the area (Imevbore and Adeyemi, 1981)

Studies show that gas flaring significantly affects not only the microclimate but also the soil physic-chemical properties of the flare sites (Alakpodia, 2000; Odjugo, 2007).

Odjugo and Osemwenkhae (2009) carried out a study on the effect on gas flaring on maize yield size and concluded the sand content of the soil, pH, bulk density, air and soil temperatures increased toward the flare site. For optimum yield of maize within the Niger Delta where gas flaring takes place, it is recommended that maize must not be cultivated within 2 km of the bund wall of the flare sites. Therefore, research findings show that there is indeed a correlation between environmental variables resulting from gas flaring and the development of certain ailments found in individuals residing in such area.

2.7.2.2 Adverse effect on revenue generation.

Nigeria, for instance loses about $2.5 bn annually through gas flaring; if stopped, such money realized could be invested into other sectors of the economy. It could even be used to start the rehabilitation of what flaring itself has damaged, or even used in providing amenities like hospital roads, as well as schools in the country. From another point of view, gas flaring has indirectly hindered foreign investors from investing in the country. This is because they (these foreign investors) tend to spend more on provision and maintenance of personal industrial power-generating plants. Even the local businessmen, artisans, small-scale business people tend to spend more on electric generation because of the nature of electric power supply in Nigeria. The gas that is wasted through flaring could be used to generate electricity.

2.7.2.3 Effects on tourism.

Continuous flaring surely leads to gradual destruction of the ecosystem of Nigeria and that of Niger Delta in particular. This degradation could inhibit tourists from visiting the country.

Tourists are attracted to serene environment, beautiful, monumental and natural places. They also need security. Because of flaring of gas, there is tension and youth restiveness in some areas of the Niger Delta and surely that can inhibit tourism. The Niger Delta is the largest wetland in the whole of West Africa and it is blessed with a variety of fresh water fish, crops and economical trees that are at risk of extinction. The heat produced and in a way the vibration has destroyed so many economic and botanical plant species. This has really made it quite difficult for the traditional healers who use herbs, bark of trees and roots for treatment of some minor ailments.

2.8 GAS FLARE MANAGEMENT TECHNOLOGIES

There are available technologies for the management of flare gas**:** though their optimal usage might not be in full application, these are great potentials to the reduction of gas flaring, by applying certain policies and strategies. Odumugbo (2010); Indriani (2005); Thomas and Dawe (2003) outlined some technologies that could be vital in the reduction of gas flaring, and those technologies are systematically reviewed and also exhibited in Figure 2.8.

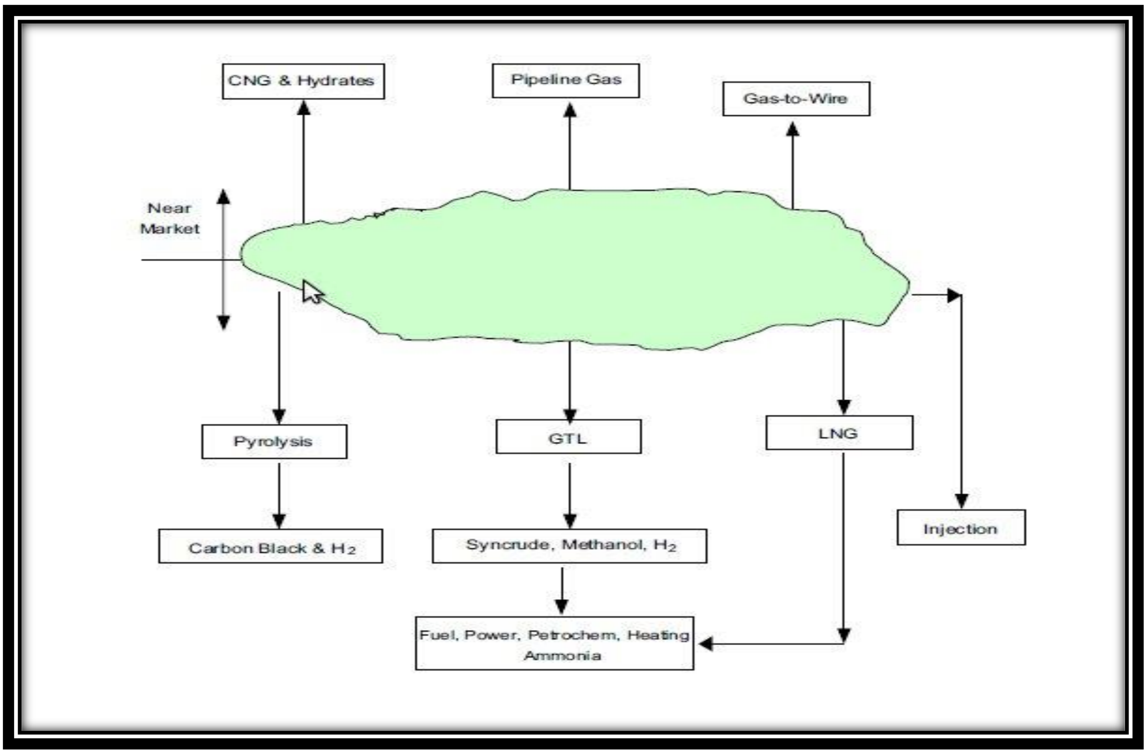

Figure 2. 8: Natural Gas Transport and Development Alternatives (Odumugbo, 2010).

2.8.1 Gas-To-Liquid (GTL) Technology

This involves the conversion of natural gas or other forms of gaseous hydrocarbons into longer-chain hydrocarbons like diesel fuel or gasoline. This process produces diesel fuel with almost same energy density to the conventional diesel, but possesses a higher cetane number, and thereby permits or supports better performance engine design (Stanley, 2009): therefore with this quality in mind, the GTL adds values, but also provides products that could blend well with the conventional products and at the same time having lesser pollutants. It is also worthy to note that in Russian literature, GTL is substituted with synthetic liquid fuel (SLF) (Eliseev, 2008). To achieve this process, two broader technologies are involved and they are direct conversion from gas and indirect conversion through synthesis gas (SYNGAS). The direct technology involves the conversion of methane, thereby eliminating the cost for the production of synthesis gas. However, this calls for higher activation energy and could be quite hard to control. The indirect technology could take place through Fischer-Tropsch (F-T) synthesis or through methanol. The F-T process involves a chemical process whereby catalysts (like cobalt or iron) are used to synthesize complex hydrocarbons from simpler organic chemicals (Shell, 2009). This F-T process is further categorised into two namely: The High Temperature Fischer-Tropsch process technology (HTFT): the catalyst utilised here is iron and takes place in temperature that ranges between 300 – 350^{o}C. According to Anyadiegwu *et al.,* (2014), this particular process is associated with the production of petrol (gasoline) and gas oil with aromatics and almost a zero Sulphur; and the second category is the Low Temperature Fischer-Tropsch (LTFT) process technology, which utilises cobalt as the catalyst within temperature level of about 200 – 240^{o}C: the product from this process is known as GTL Fuel, which is a clean synthetic fraction of gas oil that is devoid of aromatics and Sulphur Anyadiegwu *et al.,* (2014). Figure 2.9 is a schematic of the Fischer- Tropsch Synthesis: highlighting a flowchart of the process and the final products – liquefied petroleum gas, naphtha and diesel (Rahmim, 2005).

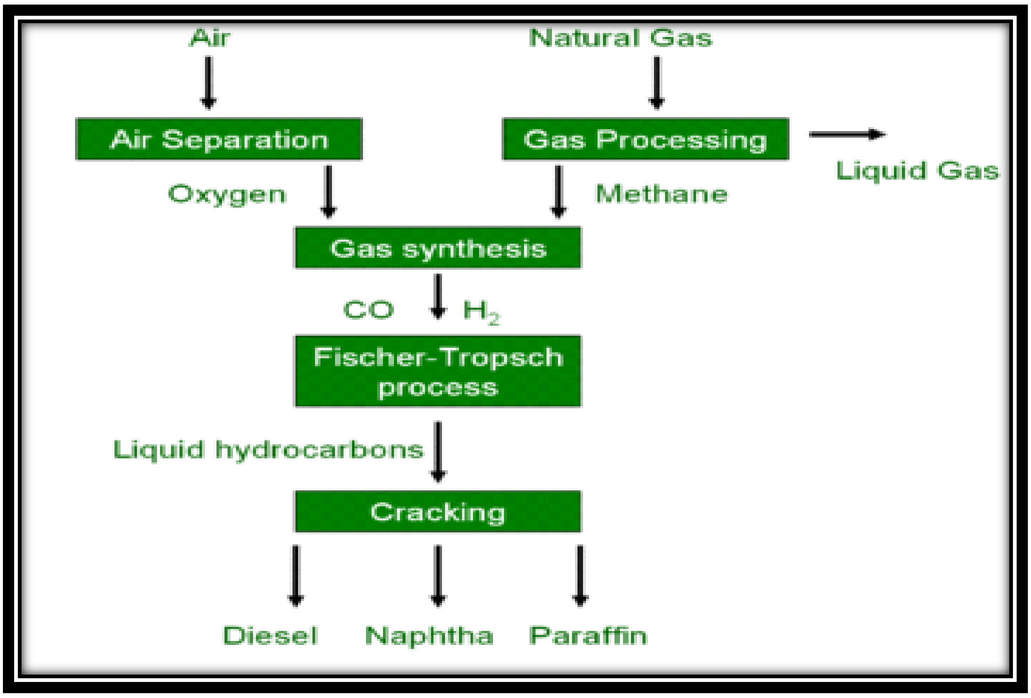

Figure 2. 9: A simplified GTL F-T Process (Modified from Rahmim, 2005).

According to Rahmim (2005), the earliest commercial usage of GTL was during the Second World War by the Germans, and then seconded by South Africa in the 1950s. According to Genovese *et al.*, (2005), from a geographical point of view, the areas interested in GTL projects are those in which gas constitutes a critical resource for economic development, such as the Far East (Indonesia and Australia), the Persian Gulf (Iran and Qatar), Africa (Egypt and Nigeria), Latin America (Trinidad and Venezuela), the North America (Alaska). The GTL projects are often implemented in existing industrial sites (José in Venezuela and Point Lisas in Trinidad) or in synergy with LNG plants (Shell in Indonesia and Egypt). Shell applied the F-T process successfully in Malaysia in the 1980s and it is been used to convert natural gas to fuel in a GTL Plant in Bintulu (Stanley, 2009). However, the use of GTL as a means of reducing gas flaring could have some drawbacks in some countries, particularly Nigeria because, the gas and oil wells are scattered in different and far away destinations (Tolulope, 2004). So this may be capital intensive because it will surely require the construction of extensive pipeline network, which is necessary for the onward movement and delivery of gas to the industrial facility for the conversion.

2.8.2 Liquefied Natural Gas (LNG)

LNG is a technology that is effective in the transportation of gas for long distances, particularly overseas; it is responsible for about 25% of the world gas movement (Deshpande and Economides, 2005). LNG is natural gas (mostly CH_4) which has been converted to liquid form, for easier transportation and storage. To become finished goods, it passes through several processes ranging from removal of impurities to refrigeration and distillation, liquefaction, removal of nitrogen content, before being stored and ready for transportation (Paltrinieri *et al.*, 2015), as duly represented in Figure 2.10.

Apart from the ideal situation of long-term contracts/agreements, LNG development is currently characterized by large investments in liquefaction facilities and LNG carriers (Odumugbo, 2010). Also, LNG production plants, to date, have been sited only onshore due to their large-scale technical complexity and overall economics. Therefore, the viability of developing remote offshore gas via LNG is determined by the economic limit of transporting the gas to shore. Following some initial processing, the gas undergoes a liquefaction process using some variation of a cascade cycle. The gas liquefies at a temperature of approximately -256˚F (-160˚C) and is converted to LNG (Economides, 2005). Conventional LNG plants require large feed gas volumes, in the range of 450 - 600 million standard cubic feet per day (MMSCFD) or 3.8 - 5.5 mtpa (metric tons per annum) per LNG train. Therefore substantial investment in upstream gas gathering will be required in order to develop small remote gas reserves into onshore LNG. These factors limit the prospects of developing remote stranded gas via conventional LNG (Akachidike, 2008).

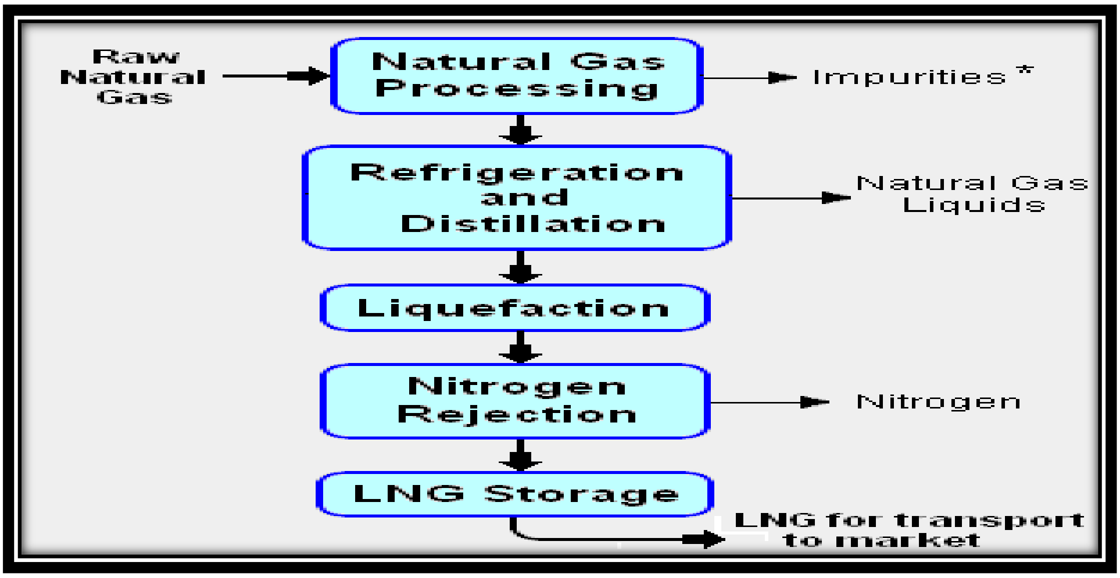

Figure 2. 10: Block Flow Diagram of LNG Liquefaction (Indriani, 2005)

According to Odumugbo (2010), presently, there is an ongoing development pertaining Floating Production Storage and Offloading LNG (FPSO) or Floating Liquefied Natural Gas (FLNG) facility for offshore applications. Rated capacities of current FLNG concepts are smaller (1.0 - 2.0 mtpa) when compared to the conventional LNG plants which rates about 3.0-8.0 mtpa. The FLNG concept could suitable fit remote offshore gas reserves because some developers claim to achieve cost reduction of about 30 - 40% of unit capital cost compared to a standard onshore liquefaction project. However, FLNG is considered an unproven technology. Although it is readily acknowledged that the concept is simply a combination of such proven technologies as gas liquefaction and floating production and storage systems, the fact still remains that FLNG is still considered an unproven technology. The major concerns over FLNG have been in regards to reliability and operational safety, including concerns for containment, side-by-side loading/offloading and mooring. In general, the application of FLNG has been limited by apparent technical and commercial risks, in addition to regulatory framework uncertainties.

The LNG Project is Nigeria's most ambitious natural gas project presently and boasts of about 400 MMSCFD of LNG yearly. It was completed in 1999 for the cost of about $3.8bn and located in Bonny, Rivers State (Odumugbo, 2010).

2.8.3 Gas Re-Injection/Recycle

Re-injection or Recycle is often applied offshore in order to boost oil recovery by maintaining reservoir pressure and simultaneously reduce or eliminate the need for gas transportation facilities. Also this process requires a pressure of up to 700 bar or 70,000 KPa (Jahn *et al.*, 2001). This is still an attractive option for small volumes of associated gas aimed at utilizing small volumes of gas, which previously were flared because of the relatively small volume produced. It is often used in cases where investment in processing or export infrastructure would render the prospect uneconomical. However, for reservoirs with substantial gas reserves, re-injection is often considered uneconomic. It should be mentioned that water injection is the commonly used technique to boost oil recovery. However gas re-injection or recycling is a viable alternative to gas flaring.

A typical gas re-injection process is shown in Figure 2.11 below, which is the "Sanha Condensate Project" in Angola, which is expected to eliminate flaring from existing platforms, and at the same time increase the production of oil by gathering, processing and re-injection of associated gas (Shinn, 2004).

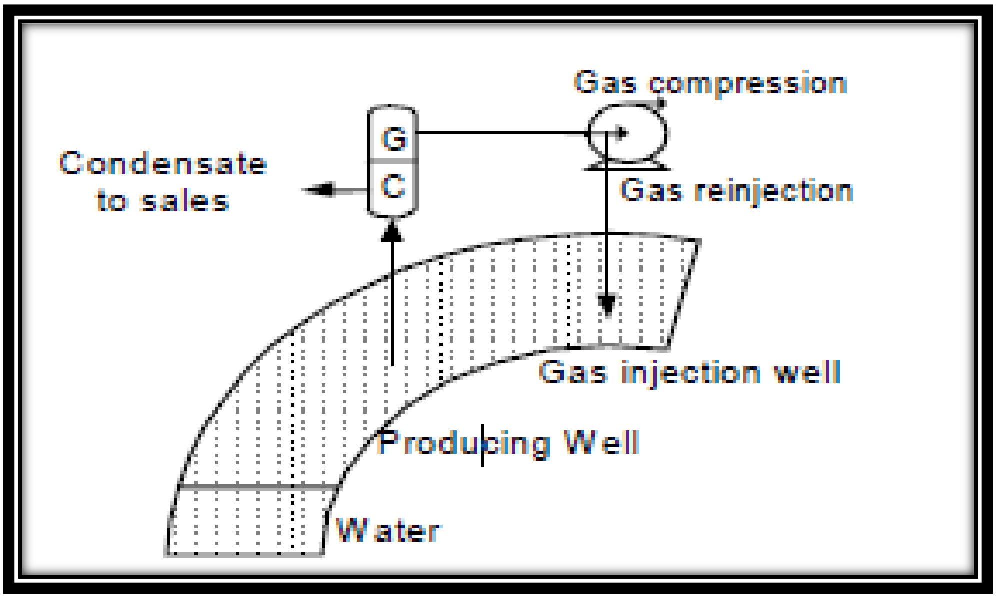

Figure 2. 11: Schematic drawing of Gas re-injection process (Indriani, 2005)

By its completion, it will produce up to 100,000 barrels per day of oil, condensate and LPG (ChevronTexaco, 2004). And also, the condensate and the LPG will be extracted from 650 million cubic feet per day of gas. With the addition of associated gas from the surrounding platforms, the complex will separate the high-value hydrocarbon liquids from the gas.

At times, companies can also inject gas back into the reservoirs to maintain pressure and help force out more oil. This process is used in so some Western countries and also in some developing countries. For instance, in Gabon the government and its partner, Shell, recently added equipment to re-inject gas, reducing CO_2 emissions by a total of 1.1 million tonnes (Broere, 2008). The Rabi oilfield in southern Gabon is a case in point. Flaring of about 0.6 million tonnes of natural gas per year was reduced to 0.02 million tonnes by upgrading existing compressors and installing new ones. The technique doesn't work everywhere, however. In shallow reservoirs, for example, adding too much pressure can lead to an uncontrolled flow of oil, gas or water.

2.8.4 Gas-To-Methanol

This is a synthetic fuel produced by synthetic gas and methanol synthesis processes. Gas-to-Methanol like other synthetic fuels can utilize existing liquid (oil) storage and transport infrastructures relatively easily. From the report of the research by Odumugbo (2010), there is a limitation on the methanol market, which has inhibited its development. A most profound benefit of Gas-to-Methanol development is the very wide array of product value- chain derivable from the process, such as methanol to gasoline (MTG), methanol to olefins (MTO), methanol to olefins to gasoline and distillates (MOGD), dimethyl ether (DME), methanol to power (MTP) etc. A schematic of gas-to-methanol is shown in Figure 2.12.

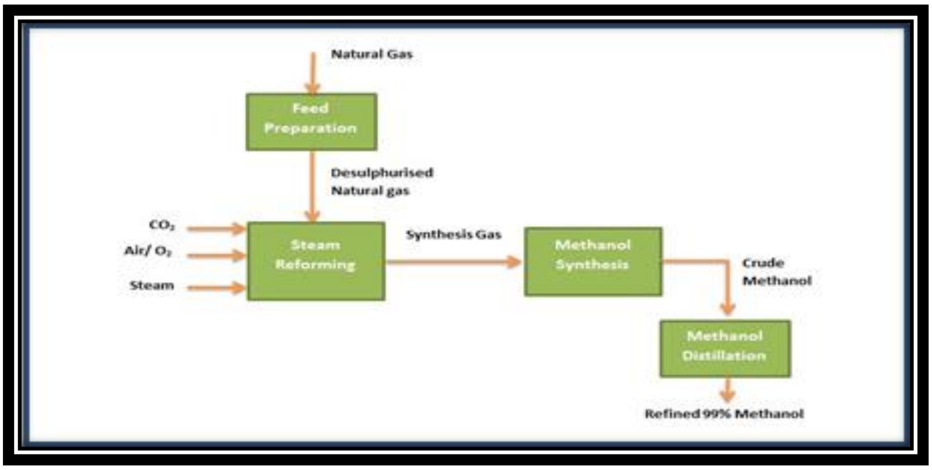

Figure 2. 12: Methanol: Trinidad's Methanol Industry (Ministry of Energy and Energy Industry, 2016)

2.8.5 Pipeline

This is a good means of transporting natural gas globally to the end users; and it is still in practice till date (responsible for about 75% of globally transported gas). This technology is also convenient and economical for onshore purposes (Deshpande and Economides, 2005).

Pipeline is the principal and most convenient method of transporting gas: either from an offshore location to onshore for processing or to interface with existing distribution grids. It is also used for transportation of export gas. Nevertheless, for offshore transport of natural gas, pipelines become challenging as the water depth and the transporting distance increase. And it now becomes important to state that distance determines the economics of gas transportation (Durr *et al.*, 2007). An application of this technology is the West African Gas

Pipeline (WAGP) as shown in Figure 2.13. Its ultimate capacity is estimated to be about 400 million standard cubic feet (SCF) per day, and supplies gas for electricity generation to Benin Republic, Togo and Ghana from Nigeria (Shinn, 2004).

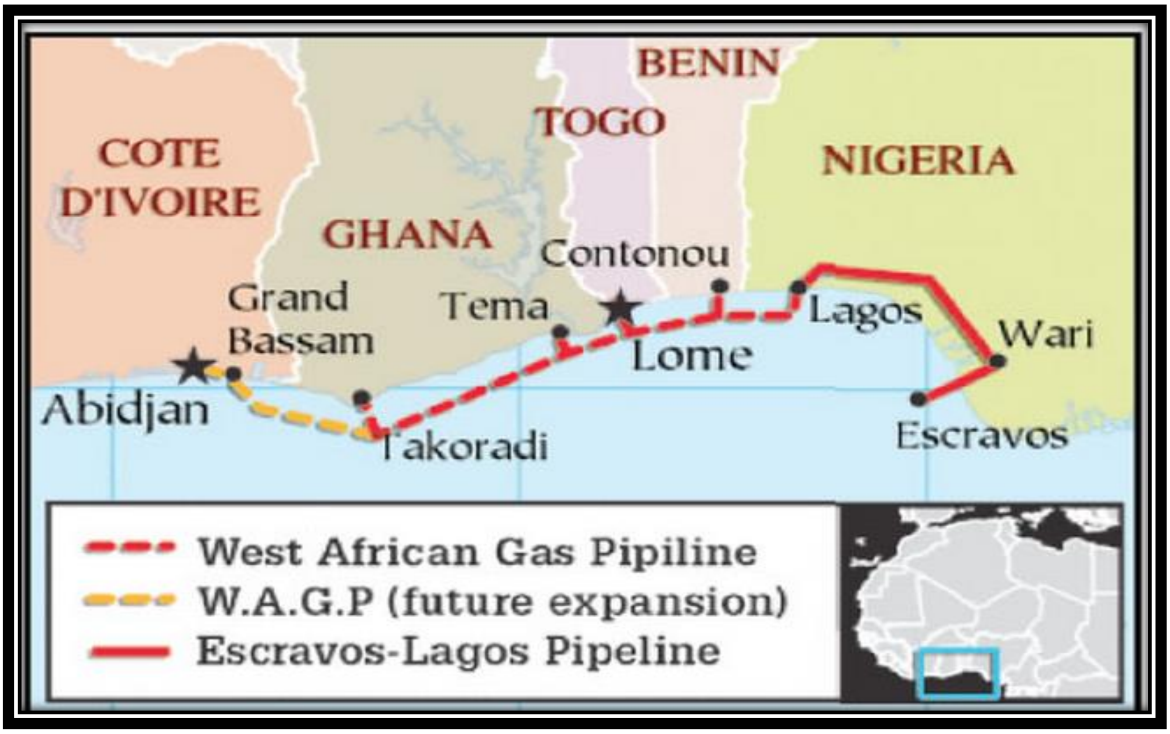

Figure 2. 13: The West African Gas Pipeline (WAGP) Project (FEIGR, 2015).

According to Indriani (2005), this technology is associated with numerous benefits, like reduction in flaring by using associated gas as alternative fuel, reducing air pollution and improving health. However, it also has its own barriers like, policies and regulation issues, namely government support, pricing, taxation and regulatory structure. In addition, financial problems might rise if the investment is high but profitability remains questionable. Current and future markets will influence the feasibility of the project, as well as the possibility of leakage and boundary determination.

However, these technologies are also facing some certain shortfalls. These have been highlighted in Table 2.3 and identified as disadvantages.

Table 2. 3: Disadvantages of specific gas management technologies (Dawe, 2003; Odumugbo, 2010)

Gas Management Technology	Disadvantages
Pipeline	• Vulnerable to sabotage. • Faces difficulty due to political boundaries. • Gas is not readily stored
Gas-to-Wire (GtW)	• Installing high power lines to reach the shoreline could be very expensive. • Loss of energy from cables along distant transmission lines
Liquefied Natural Gas (LNG)	• Requires complex machinery with moving parts. • Capital intensive project
Gas To Liquid (GTL)	• Still at primordial stage. • Very capital intensive. • Raw materials for conversion to commodity (silica sand, limestone) might prove difficult to import to site.

2.8.6 Gas to Electricity

This means generation of electric power by using natural gas as source of fuel. However, other equipment such as turbines, which are the prime movers are also involved. And for this study, we refer to it as gas to wire (GTW). Basically, GTW is a technology that involves the use of gas to power/fuel a turbine, thereby generating energy. Electricity production with power cycle is one of the common methods for eliminating gas flaring. The basic principle of the power cycle requires burning gas in a gas turbine (GT) and producing power which can be converted to electric power by a coupled generator. This type of power plant is installed in increasing numbers around the world where substantial quantities of natural gas is abundant (Rahimpour et al., 2012). It produces high power outputs at high efficiencies and low emissions.

2.8.6.1 Structure and operating principles of a gas turbine (Brayton cycle)

Typically, a gas turbine operates on the 'open cycle', with internal combustion as seen in Figure 2.14. Air and fuel gas pass across the single control surface into the compressor and combustion chamber respectively, and the combustion products leave the control surface and expand through the turbine.

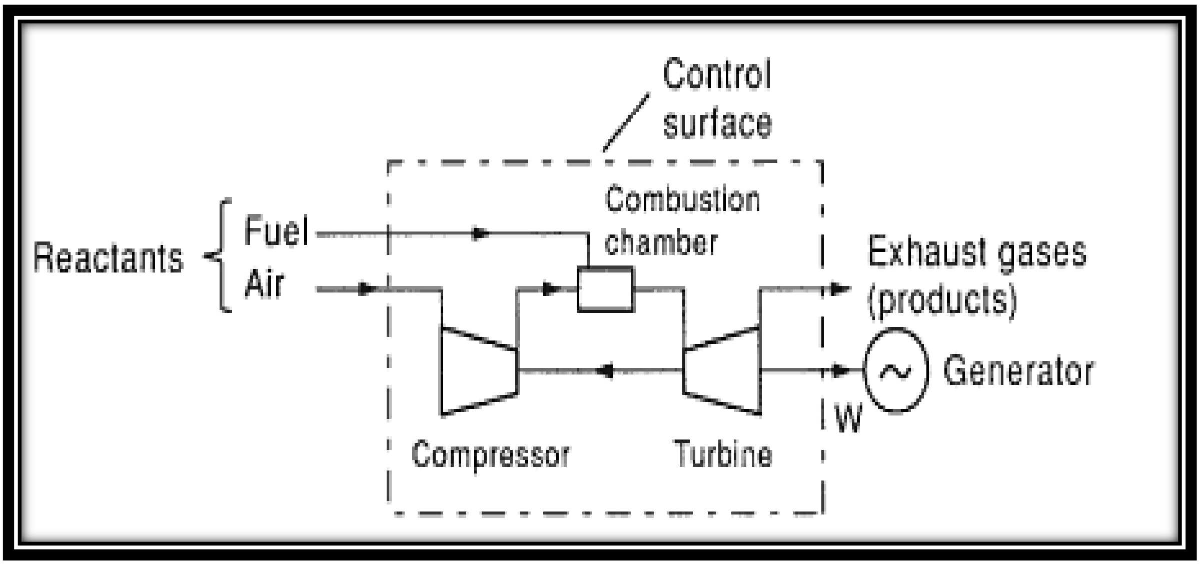

Figure 2. 14: The Open Circuit gas plant (Jansohn, 2013)

The utilization of gas turbines in the simple-cycle mode has been limited to a certain amount of electricity generation. However, according to Poullikkas (2005), the industrial gas turbines have improved with respect to fuel-to-electricity conversion efficiency, plant capacity reliability as well as availability. Najjar (2000) in a study further states that the increase in distribution of gas turbines for base load application is associated with the availability of gas, lower capital investment as well as advanced cycles. The functionality and thermodynamics of this cycle are demonstrated further in Section 2.8.6.2.

Two major ways that GTW technology could be achieved are combined heat and power (CHP) and combined cycle gas turbine (CCGT).

- In CHP, the heat that is produced during electricity production is captured and re-used. According to Marcecki (1988), CHP system deals with the simultaneous cogeneration of electrical and heat energy in the form of low-pressure steam or hot water. In a research by Pilavachi (2000), it is stated that the CHP technology is characterized by devices that are capable of converting heat energy into mechanical energy; engines, that could be operated with gas, diesel or bio-diesel; turbines, that could be operated with gas, fuel, steam, combined gas and steam system; or fuel cells, that could be operated with fuels obtained from natural gas.

A typical CHP system consists of an electric generator, which can take the form of a gas turbine, steam turbine, or combustion engine. In addition to this electric generator, a waste heat exchanger is installed, which recovers the excess heat or exhaust gas from the turbine and converts it to steam or hot water. There are two basic types of CHP systems. The first is known as a 'topping cycle' system, where the system generates electricity first, and the waste heat or exhaust is used in an alternate process. Three basic types of topping cycle systems exist. The first, known as a combined-cycle topping system, burns fuel in a gas turbine or engine to generate electricity. The exhaust from this turbine or engine can either provide usable heat, or go to a heat recovery system to generate steam, which then may drive a secondary steam turbine. The second type of topping cycle system is known as a steam-turbine topping system. This system burns fuel to produce steam, which generates power through a steam turbine. The exhaust (left over steam) can be used as low-pressure process steam, to heat water for example. The third type of topping cycle system consists of an electric generator in which the engine jacket cooling water (the water that absorbs the excess emitted heat from an engine) is run through a heat recovery system to generate steam or hot water for space heating. The last type of topping cycle system is known as a gas turbine topping system. This system consists of a natural gas fired turbine, which drives a generator to produce electricity. The exhaust gas flows through a heat recovery boiler, which can convert the exhaust energy into steam, or usable heat.

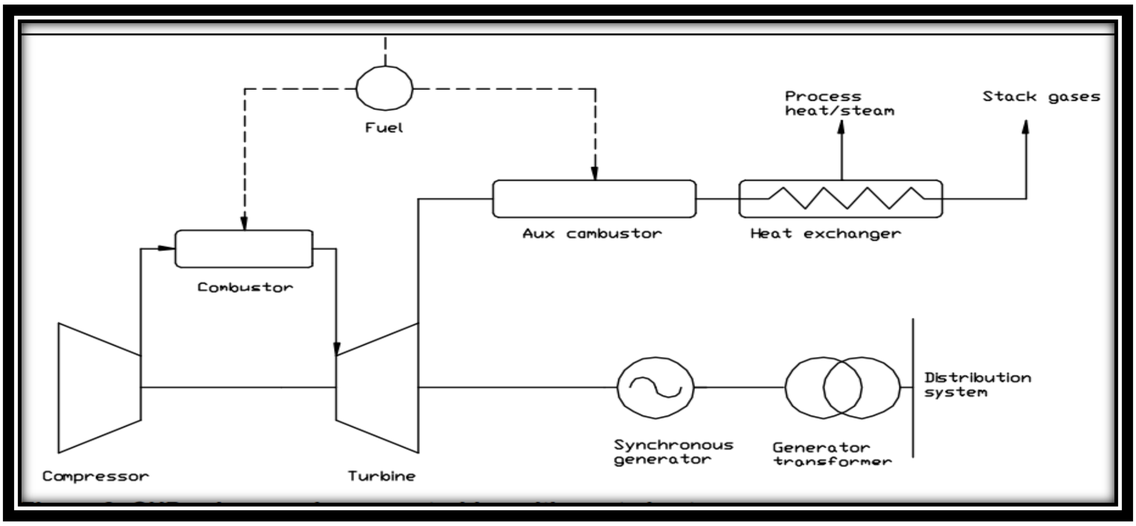

Figure 2. 15: CHP scheme using a gas turbine with waste heat recovery (Jansohn, 2013)

However, there is another type of CHP system known as ‘bottoming cycle’ systems. This type of system is the reverse of the above systems. Excess heat from a manufacturing process is used to generate steam, which leads to electricity generation. This type of system is common in industries that use very high temperature furnaces, such as the glass or metals industries. Excess energy from the industrial application is generated first, and then used to power an electric generator.

- Combined Cycle Units: Many of the new natural gas fired power plants are known as ‘combined-cycle’ units. In these types of generating facilities, there is both a gas turbine and a steam unit, all in one. The gas turbine operates in much the same way as a normal gas turbine, using the hot gases released from burning natural gas to turn a turbine and generate electricity. In combined-cycle plants, the waste heat from the gas-turbine process is directed toward generating steam, which is then used to generate electricity much like a steam unit. Because of this efficient use of the heat energy released from the natural gas, combined-cycle plants are much more efficient than steam units or gas turbines alone. In fact, combined-cycle plants can achieve thermal efficiencies of up to 50 to 60 percent (Natural Gas.org, 2013). Figure 2.16 is a schematic demonstration of a simple combined gas turbine.

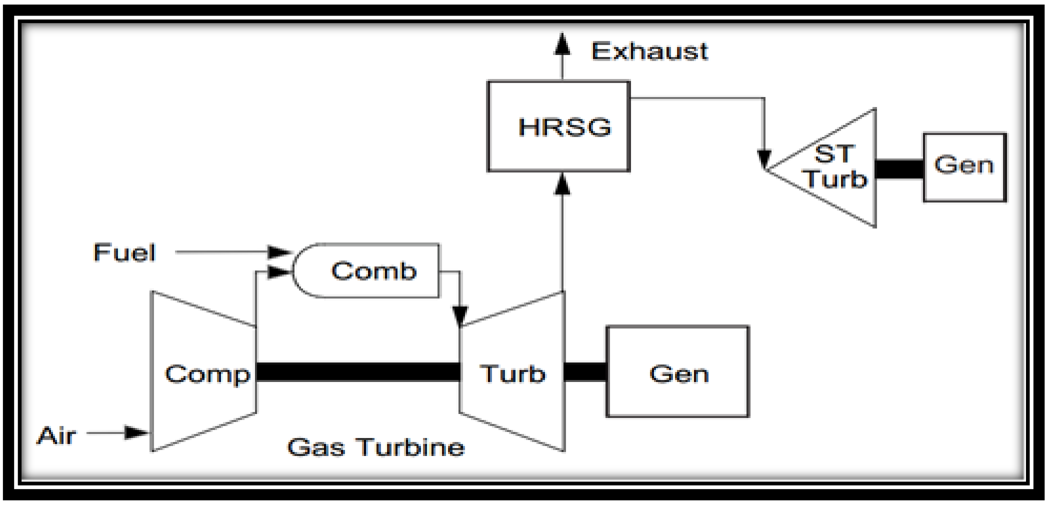

Figure 2. 16: Schematic Diagram of Simple CCGT (Jansohn, 2013)

The Heat Recovery Steam Generator (HRSG) serves as a link up for the gas and steam turbines (ST). Heat from the gas turbine exhaust generates steam by passing it through a labyrinth of water-filled finned tubes. It produces steam at three separate pressure levels: high pressure (HP), intermediate pressure (IP) and low pressure (LP) for use in each pressure section of the turbine. Steam from the HRSG runs through a multi-stage turbine to spin an output shaft that drives the plant's generator.

2.8.6.2 Thermodynamic Valuation of Gas Turbine

The basic principle of the power cycle requires burning gas in a gas turbine (GT) and producing power which can be converted to electric power by a coupled generator. This type of power plant is installed in increasing numbers around the world where substantial quantities of natural gas is abundant (Rahimpour *et al.*, 2012). It produces high power outputs at high efficiencies and low emissions. Gas turbines can also be used in simple cycle mode for base load mechanical power and electricity generation in the oil and gas industries where natural gas and process gases have been used as fuel and their maintenance costs are much lower than those for liquid fuels. The Brayton cycle of a gas turbine was analytically studied, and this demonstrated the functionalization of the gas turbine. This research studied the basics of thermodynamics of gas turbines and this created more information on with the concepts.

This research also studied and understood the importance and impacts of pressure and temperature on the thermal efficiency of the turbine. During the data collection process, a closer viewing of a real life gas turbine was carried out and this provided a clearer practical understanding of gas turbine functionalization. Figure 2.17 is a real-life gas turbine from a power station (one of the case studies) during data collection session in Nigeria.

Figure 2. 17: A Real-Life Gas Turbine system

Figure 2.18 conceptually shows a simple thermodynamic cycle that in principles is made up of very small set of components. It is made up of four processes, with either a gas or a mixture of gases as working fluid. The first process is known as an adiabatic compression, the second process is the heat supply at constant pressure, the third process is an adiabatic expansion, and the fourth process is known as a release heat at constant pressure. The cycle is also made up of two adiabatic and two constant processes. This cycle could either be an open gas turbine cycle or a closed gas turbine cycle.

Furthermore, this could be illustrated with the help of a T-s diagram as shown in Figure 2.19. It highlights the functionality of a Brayton cycle which is one of the most efficient cycles for the conversion of gas fuels to mechanical power or electricity. At entry point 1, the air which enters the plant comes from the atmosphere to the compressor where the pressure is ramped up from atmospheric pressure to 23 bar. At point 2, the compressed air then passes to a combustion chamber and blended with natural gas where combustion takes place. At point 3 of the cycle, hot gases are directed to the gas turbine where they expand to the atmospheric pressure and the gas energy is converted to mechanical energy which generates electricity. Exhausted gases are subsequently discharged from the gas turbine at point 4 of the cycle.

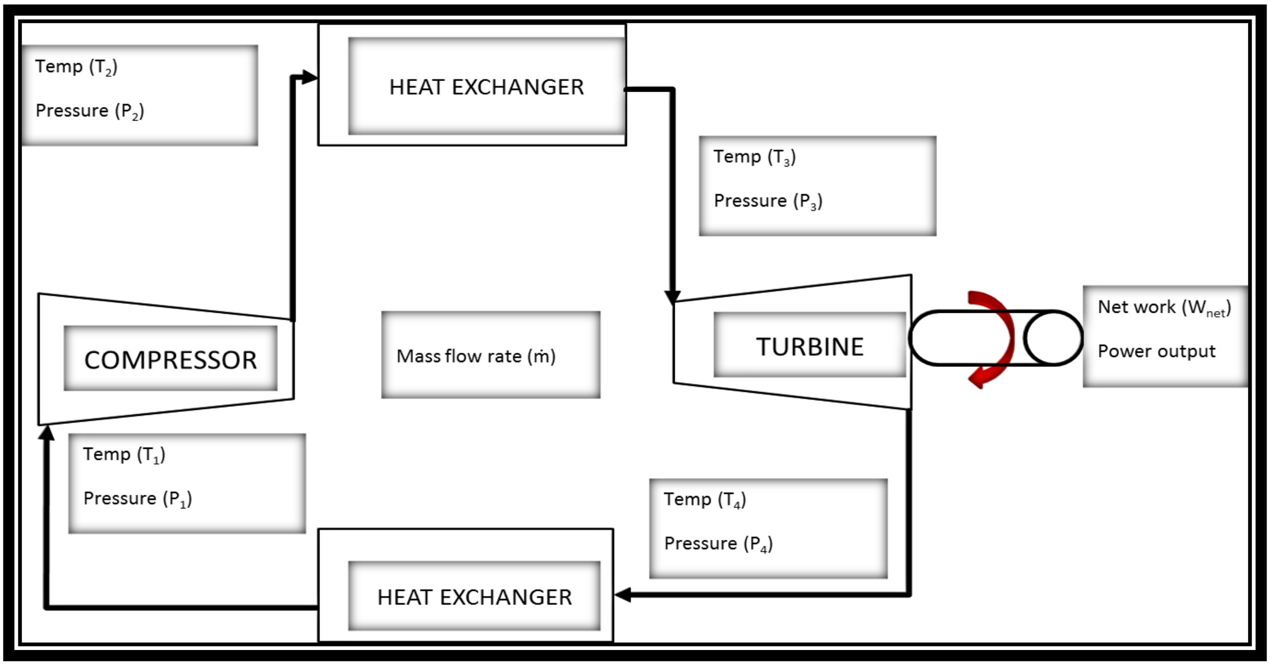

Figure 2. 18: A Flowchart of the Brayton cycle (Adapted from Rahimpour *et al.*, 2012)

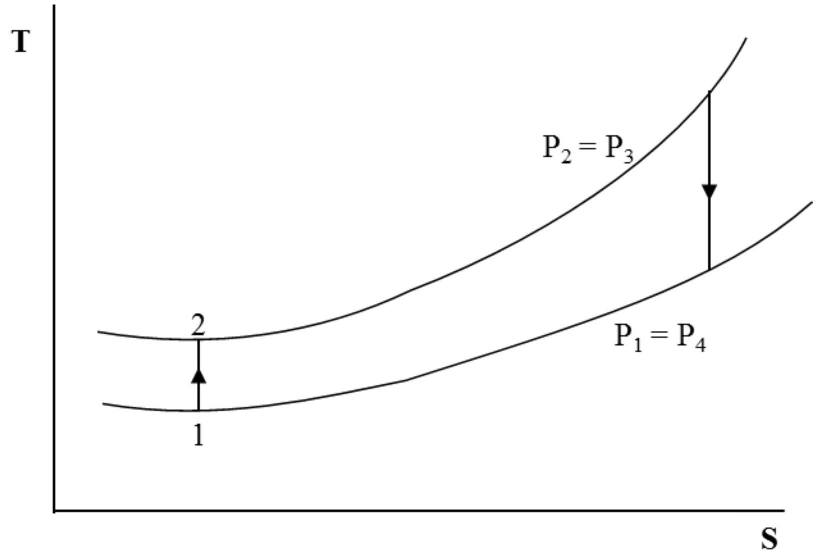

Figure 2. 19: T – S Diagram illustrating the stages in Joules-Brayton cycle (Adapted from Learn Thermo.com, 2014)

These studies supported this research to appreciate thermal efficiency and work outputs which are vital in any given gas turbine as shown in the successive equations. They also

Generally, in the determination of the performance of a cycle, two parameters are evaluated, and they include the thermal efficiency and the work output. In the closed cycle, the thermal efficiency is mathematically determined as follows:

$$n = \frac{w}{Q_1}$$

Where Q_1 is the heat supplied to the cycle and W is the work output. Also with regards to a closed cycle (considering the fact that the first principle of thermodynamics states that $W = Q_1 - Q_2$); where Q_2 is the heat released from the cycle: therefore the efficiency could also be expressed as follows:

$$n = \frac{W}{Q_1} = \frac{Q_{1-}Q_2}{Q_1} = 1 - \frac{Q_1}{Q_2}$$

The work output of a cycle is described as the difference between the expansion and the compression. In a closed cycle, the fluid which expands in the expander possesses same flow rate and composition as the fluid being compresses in the compressor. This is mathematically expressed with the equation:

$$W = W_T - W_C$$

The gas turbine has its advantages, which include but not limited to the following:

- ✓ Fuel flexibility: the gas turbine has the capability to burn various qualities of gases than other reciprocating engines.
- ✓ Lesser number of moving parts: with lesser moving parts comes cheaper cost of maintenance.
- ✓ Higher availability
- ✓ Lesser vibration as well as noise.
- ✓ It is compact

2.9 CONCEPTUAL FRAMEWORK

After reviews of literature on gas flaring and practices, the study has come up with a conceptual framework. It put into consideration the role of government policies as well as partnership between the oil and gas producing companies and government, which will be effective and beneficial in the management of sustainable gas flaring. First and foremost, the government has to be actively and practically involved, through the promulgation of policies that could attract some more private investors and also motivate the existing oil and gas operators (Policy and Agreement). Government involvement could also be demonstrated in the form of tax holidays and reduction. These could be given to firms (multinationals or local) who are willing to invest in flare gas reduction as a form of encouragement. This is expected to create a different point of view for the oil and gas firms, on how they handle the 'flared gas' (Change in Perception). Due to incentives that are associated with the government policies, they are mandated to sustainably manage the flare gas. As shown in the conceptual framework, the government policies and agreement with oil and gas producing firms will drive flare gas management. Two ways to execute this are either to minimize volume of flare gas or to continue flaring without minimization. If the volume of flaring is not minimized, the adverse impacts continue and can potentially get worse. However, to minimize the volume of flare gas, a gas reservoir is required to gather flare gas. Subsequently, this could be used for electricity generation as fuel for gas turbines. The electricity that is generated could be used in major ways – internal use, whereby it is solely used in the oil and gas exploration site for drilling purposes and lighting; external use, whereby the generated energy is completely transferred to the national grid. A schematic of the conceptual framework is shown in Figure 2.20.

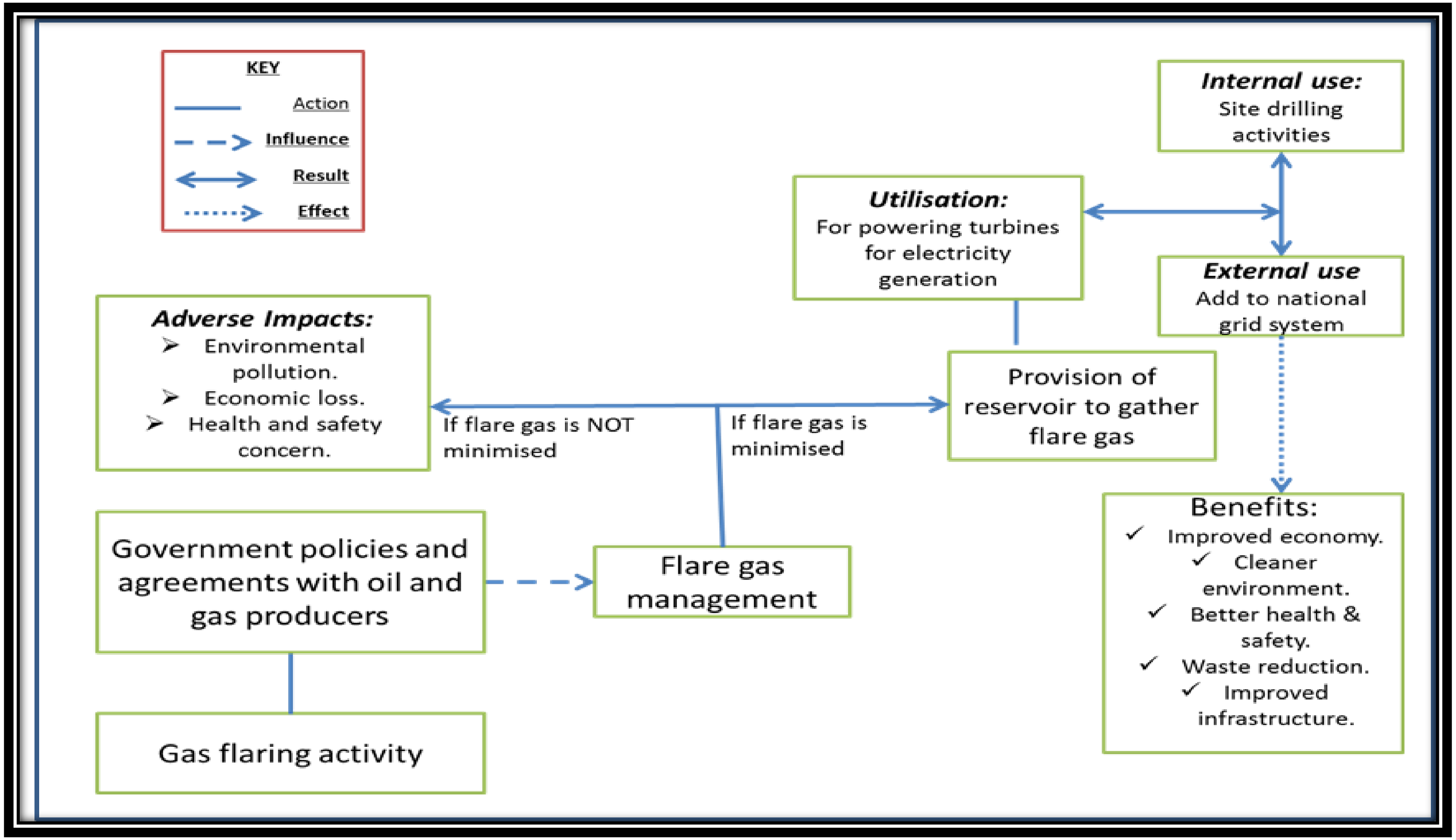

Figure 2. 20: Conceptual Framework for Flare Gas Management

2.10 SUMMARY

Huge volume of gas is wasted globally on a yearly basis through gas flaring. This waste is enough to provide the electricity need for the entire African continent. Countries like Norway, Canada, and Netherlands have effective measures to tackle the menace of gas flaring; while a lot of other crude oil and gas producing countries like Russia, Nigeria, Qatar, Ecuador do not have such efficiency and therefore still flare so much. But the irony of the matter is that more than half of the Nigerian population lives in either total or partial lack of electricity, yet Nigeria is the second largest flaring country.

Nigeria is rated among the top gas-flaring countries with an annual gas flare of 15.2 billion cubic meters (see Giwa *et al.*, 2014; M.E.E., 2012; Akachidike, 2008), and accounts for about 16% of global gas flare (US Energy Information Administration, 2013). The lack of gas utilization infrastructure in Nigeria has resulted in flaring of about 75% of the associated gas with just 12% of produced gas re-injected back into sub-surface reservoirs (Ahmed *et al.*, 2012). Official data for 2004 indicates that Nigeria lost over 8.5 TCF of natural gas as a result of flaring during that year alone (Petroleum Economist, November 2007). This volume of gas is equivalent to about 5% of the country's total proven reserves.

Gas flaring activities pose so much negative impacts to the environment, economy and also on health and safety of the inhabitants. It is responsible for the emission of carbon dioxide and methane (CO_2 and CH_4) to the environment, as well as the introduction of acidic precipitations. Gas flaring has been associated to leukemia, bronchitis and asthma in some cases. The noise that comes from the flaring sites could cause noise pollution to the inhabitants who are nearby (Abdulkareem and Odigure, 2006). It is also a great means of economic loss and waste because if the flared gas is subjected to positive utilization, it is bound to generate financial support to the economy.

There are available technologies that could be used to harness the gas and avoid wastage. According to Odumugbo (2010), these include pipeline, gas-to-wire, re-injection, gas-to-liquid, liquefied natural gas. Although they are important, they also have their downsides or reservations which range from high capital investment to the technology being at primordial stage.

The research highlighted gas-to-wire as a viable technology for the reduction of gas flaring in Nigeria. This is because of three major reasons:

i. Nigeria is faced with the challenge of lack of electricity production. Therefore, channeling the gas towards production of electricity will provide a sustainable means of utilizing gas instead of flaring, and also solves a national problem.
ii. There are existing power stations in Nigeria as clearly stated and shown in Chapter Four (4) of this thesis. These power stations are facing extinction because of the presence of dilapidated gas turbines. In other words, there are existing structures; therefore the capital investment in Nigeria will not be very high because basically, what will be needed are gas turbines.
iii. The use of gas-to-wire will generate employment and also improve the general economy of Nigeria. It technically converts waste (flare gas) to wealth (electricity).

Finally, the study identified three major gaps in knowledge after the review of existing literature and they include the following:

i. Lack of existing gas flare management framework in Nigeria.
ii. Lack of economic evaluation of GTW technology for flared gas reduction.
iii. Lack of cordial relationship and understanding between oil and gas producing/flaring companies and electricity producing sector towards gas flare management.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the research methodology adopted for the study. It consists of various combination of processes used in search for reduction of gas flaring in an oil and gas-processing environment. It also highlights the procedures that led to the achievement of the research objectives in this study. The research onion as shown in Figure 3.1 was applied to create a balance for direction because according to Saunders *et al.* (2012), it creates a better understanding for research patterns.

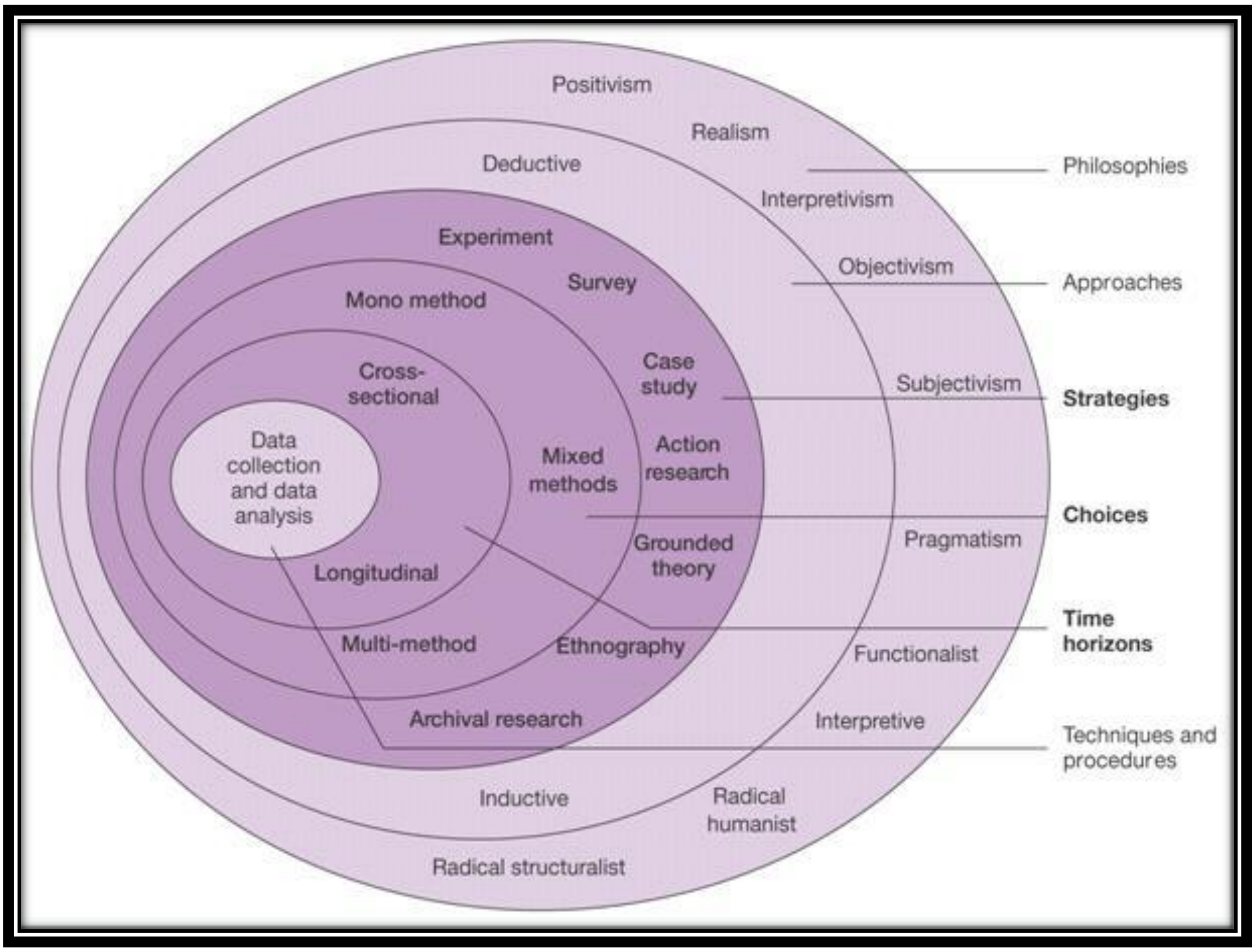

Figure 3. 1: Research Onion (Sanders et al., 2012)

3.2 RESEARCH DESIGN

Research design has been defined by different researchers with a common theme. Research design is regarded as the logical sequence linking the findings of a study to the initial research questions. To ensure the findings answer the initial questions, Tashakkori and Creswell (2008), suggests that the most appropriate design should be selected taking into consideration a number of factors. These factors, according to Saunders *et al.* (2009) determine the research design and include: research philosophy or paradigm; research strategy; methods; research questions; and the time resources available to the researcher. Using the research onion, the following sections review the factors affecting research design and make a choice for the most appropriate design for this research.

3.2.1 Research Philosophy

Philosophy is the belief and thinking of an individual concerning knowledge and how it is created and developed (Saunders, Thornhill and Lewis, 2003). Saunders *et al.* (2009) state that research philosophy is influenced by the manner in which a researcher reasons with regards to the development of knowledge and will affect the way the researcher also conducts the research. In this chapter, we can interchange philosophy with paradigm, as paradigm is an elusive concept and appears to lack a clear-cut definition (Guba, 1990; Kerlinger and Lee, 2000; Ellis and Crookes, 2006). However, Oates (2006) defines paradigm as a set of shared assumptions or ways of thinking about some characteristic of the world. The originator of the word, Kuhn (1970) is said to have applied the word in twenty-one distinct perspectives (Guba, 1990). Paradigm, therefore, has wide discipline coverage. However, in the context of discipline inquiry, the paradigm question seeks to address the general principles or the philosophical realm within which a research should be undertaken (Guba, 1990; Clarke and Dawson, 1999; Creswell, 2009; Pansiri, 2009).

According to Easterby-Smith, Thorpe and Jackson (2008), philosophical positions are important in a study because they help in defining the research design, the type of evidence that is required, how it will be gathered and interpreted, and how this will provide answers to the research questions. They also help the researcher to identify the particular research design that will work for a particular study. Thirdly, they help the researcher to create designs that may not be related to the researcher's experience, if necessary.

There are different types of research philosophies, however according Saunders et al (2012), three philosophies are the most popular as have been highlighted with key details in Table 3.1. After thorough consideration, this research adopted the interpretivist approach as duly described in Section 4.3 of this thesis.

Table 3. 1:Three major types of research philosophy (Saunders et al., 2012)

Philosophy	Brief Description	Type of Data	Ontology	Epistemology
Positivism	Aims to highlight scientific method. Applies deductive reasoning, empirical evidence and hypothesis testing	Quantitative data, surveys based on scientific methods, larger sample sets	Objective and independent of one's subjective experience	Knowledgeable ideas which are communicable between agents
Interpretivism	Vital for the study of people, particularly in social sciences. This starts from position that the subject matter is fundamentally different from non-human subjects	Primarily requires qualitative data and may involve small number of respondents and detailed interview. This requires experience.	Depends on plenty of subjective experiences. Does not exist independently on experience	There is no possibility of objective knowledge, rather it is all about different experiences
Pragmatism	Share main assumptions of positivism, but takes a more realistic perspective.	Qualitative, quantitative and mixed methods.	Knowledge is bound by individual experience	

3.2.2 Research Strategy

As defined by Creswell, research strategy is defined as the approach used in conducting a research. Research strategies are linked to the philosophical positions which form the basis for the research. For this reason, the three research paradigms discussed above are linked to the three main strategies adopted in conducting any research. The strategies include: qualitative, quantitative, and mixed strategies which relate to the interpretivist, positivist and pragmatist philosophical positions respectively.

3.2.2.1 Quantitative research method

This is also known as scientific, traditional and conventional research methodology (Guba, 1990; Kerlinger and Lee, 2000; Khakee, 2003), and dominated research until the 1970s (Clarke and Dawson, 1999; Khakee, 2003). This method is originally rooted in positivist claims to knowledge, which in itself is underpinned by empiricist tradition (Guba, 1990; Clarke and Dawson, 1999; Kerlinger and Lee, 2000; Creswell, 2009). These claims to knowledge advocate that the rationale for research is to expand verifiable knowledge. That is, knowledge allows explanation, prediction and understanding of empirical reality construed as the only reliable knowledge that can improve human condition (Frankfort-Nachmias and Nachmias, 1996; Khakee, 2003). This notion is based on realist ontology, which suggests the existence of single objective reality in the world; absolute truth driven by immutable natural laws independent of human perception (Clarke and Dawson, 1999). However, with the emergence of post-positivism following nineteenth century works from the likes of Comte, Durkheim, Newton and, more recently, Phillips and Burbules (2000), the quest to achieve absolute truth; being ‘positive’ is said to be non-realizable (Creswell, 2003, 2009:p7). Phillips and Burbules (2000), for example, argue that knowledge is conjectural and anti-foundational, which signifies that evidence discovered in research is usually imperfect and fallible. Therefore, absolute truth is never attainable.

The advocates of quantitative research method are driven by the positivist and post-positivist ontological creeds, and thereby adhere to objective stance in inquiry. This requires detachment of inquirers from subject matter of inquiry (Clarke and Dawson, 1999; Creswell, 2003, 2009). The essence is to prevent all forms of biases and subjectiveness in inquiry (Babbie, 1990; Frankfort-Nachmias and Nachmias, 1996). Essentially, the quantitative research method subscribes to a deductive approach to research, where causal explanation and prediction of outcome of phenomena follow a deductive logic form. The research commences with a theory comprising a set of interconnected general propositions that sets its hypotheses on the premise of logical reasoning. This is followed by prescription of operationalisation procedure for variables or constructs in the hypotheses. The hypotheses are then tested upon collection of empirical data based on a specified standard of reliability and validity to authenticate theory or otherwise (Babbie, 1990; Denzin and Lincoln, 1998; Clarke and Dawson, 1999; Kerlinger and Lee, 2000). In this research, the quantitative method of research was vital as it supported and provided guidelines for development and successful achievement of the questionnaire surveys for the oil and gas producing host communities, and oil and gas producing companies; however, it is good to note that it cannot only be utilised for overall successful achievement of a concise case study.

3.2.2.2 Qualitative research method

This method emerged over four decades ago as an alternative to traditional quantitative research method (Guba, 1990; Khakee, 2003). This research method is underpinned by interpretivist philosophical assumptions (Creswell, 2007, 2009; Pansiri, 2009). The method is also described variously as naturalistic, constructionist, interpretivist, post-positivist, holistic-inductive (Clarke and Dawson, 1999) and comes in several designs (Wolcott 1992; Denzin and Lincoln, 2005) and include grounded theory, ethnography, case studies, narrative and phenomenology (Creswell, 2009).

However, the qualitative research method's claims to knowledge rest on relative ontology (Guba, 1990), which construes reality as multiple, divergent and interrelated. The philosophical consideration underlying the qualitative research method, therefore, professes that reality is not located in an objective external world or subjective mind of the knower, but within dynamic transactions between the two (Barone, 1992). Consequently, social constructionists hold the view that truth is a very elusive concept and cannot be objectively ascertained. Furthermore, it is perceived that reality is not a single entity. Rather, individuals and groups will construct their own versions of reality depending on their own socio-economic, political and cultural background and experiences. It is, thus, not for the researcher to identify which of them is close to the truth, but accurately record and report all the versions (Clarke and Dawson, 1999).

It is worth noting that the epistemological viewpoint of qualitative research method advocates rests on the notion that there is a fundamental difference between natural and social phenomena. As such, the method adopted to investigate natural phenomena may not necessarily be suitable for social phenomena. Therefore, the qualitative research method is inclined to inductive approach to research in which data is not collected to test hypothesis, but to derive broad generalization from observed data (Clarke and Dawson, 1999; Creswell, 2007, 2009).

Therefore, this study chose the qualitative research method as a means for the achievement of the research aim. As has been clearly identified in this study, there is a situation whereby gas is wasted and it is imperative to identify and illustrate the rightful way to prevent or at least reduce the wastage. Reasons for the choice of qualitative research method were primarily based on solving the challenge of gas flaring, which carries along environmental, economic and health and safety hazards; as well as the research objectives as identified in Chapter one, and the researcher's epistemological stance. The study aims to reduce gas flaring through conversion of potential flared gas to fuel for the operation of a gas turbine. Therefore, this study needs to obtain data not just from gas flaring environments, but also from potential users of gas such as electricity generation companies.

So the qualitative research approach is able to accept complexity and subjectivity and enables the researcher to use interviews, observations and interpretations of the phenomenon to gain insights and discover meaning about a particular experience, situation, cultural element or historical event (Myers, 2009). The qualitative approach helped the study to interact with the operators of the oil and gas industry, who are responsible for gas flaring and insights into the causes and reason for gas flaring thereby creating better understanding regarding the act of gas flaring. This supported the study to confirm gas flaring in the site, and also helped to ascertain volumes of gas production, utilization and flaring.

Using the qualitative method, this study identified the activities that lead to gas flaring and the possible means of gas flare reduction in Nigeria through the use of multiple case studies. Subsequently, apart from the initial interviews carried out, further interviews on some key personnel of from case studies 1, 2 and 3 were carried out to validate the framework for gas flare management, which this study developed in chapter 6.

3.2.2.3 Mixed research method

The mixed-methods otherwise known as multi-methodology is comparatively a recent development (Johnson and Onwuegbuzie, 2004; Creswell, 2009; Abdulai, 2010). This method basically conceived as combination of the first two methods – qualitative and quantitative

(Abdulai, 2010). It predominantly comes in three designs; sequential, concurrent and transformational (Creswell, 2003, 2009; Abudulai, 2010). Though connected to several philosophical considerations, the central philosophical consideration that drives this is pragmatism (Creswell, 2003, 2009; Johnson and Onwuegbuzie, 2004). The pragmatic philosophical stance rejects the existence of a single objective reality out there in the world as acknowledged by positivists and posits that inquiry, among others, takes place within historical, socio-economic and political context. From this philosophical standpoint, truth is what works at a particular point in time (Creswell, 2003, 2009). Consequently, researchers within this research method lay emphasis on the problem at hand and its solutions. This is because most times, "what, why and how" questions are more appropriately examined and further solved using a mixed research method approach. Therefore, the method subscribes to amalgamation of philosophies, strategies, data collection techniques to ensure solution of problems at hand (Patton, 2002; Creswell, 2003, 2009; Johnson and Onwuegbuzie, 2004; Morgan, 2007).

3.2.3 Research Approach

Theories on research suggest there are two main approaches for conducting research: through an inductive means; and through a deductive means.

3.2.3.1 Inductive Approach

Inductive approach allows a researcher to collect data and develop a theory on the result from analysis of such data. In this case the researcher develops hypotheses and theories with a view to explaining empirical observations of the real world. Empirical observations can be based on many factors; for example, they can be based on personal experience (Crowther and Lancaster, 2008). Alternatively, theories might be developed to explain observed data and information; for example, the researcher might develop theories based on observed patterns of labour turnover. All sorts and types of information and data can be used to develop theories in inductive research (Crowther and Lancaster, 2008). Figure 3.2 is a schematic diagram that illustrates the inductive approach.

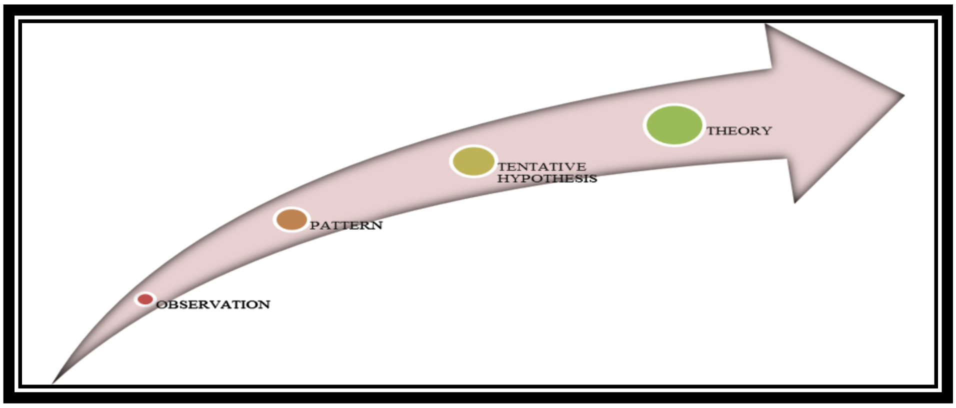

Figure 3. 2: Inductive research approach (Burney, 2008)

Crowther and Lancaster (2008) further state that one of the greatest strengths of inductive research is its flexibility. Inductive research enables flexibility in research design including aspects such as sample size and type of data and does not require the establishment of prior theories or hypotheses. On the other hand, the authors argue that a researcher can build their theory based on what is observed, thereby allowing a problem or issue to be studied or approached in several possible different ways with alternative explanations of what is going on. In line with this, this study adopted the use of multiple case studies and questionnaire surveys are means of gathering data for research. Questionnaires were distributed and received from four oil and gas producing communities to identify the impacts of gas flaring in those communities; and questionnaires were also distributed to three oil and gas producing companies, as this process helped this research to highlight the processes of gas production, utilization and flaring in Nigeria. The case studies were carried out on two electricity generating companies, which this research tagged CS-2 and CS-3, and an oil and gas producing company which is tagged CS-1.

Crowther and Lancaster (2008) also noted that inductive research is suitable for studying human behaviour in organisations. However, Saunders *et al.*, (2009) stress that inductive research can be much more protracted. The authors argue that inductive research takes a longer period for data collection and analysis has to emerge gradually. With inductive research, there is fear that no useful data patterns or theory will emerge (Saunders *et al.*, 2009). It is vital to note that the processes of induction and deduction are not totally exclusive of each other: in other words, induction includes elements of deduction and vice versa (Ghauri and Grønhaug, 2005). Quinton and Smallbone (2006) also state that there is not such a sharp divide between the two research approaches.

According to Jankowicz (2005), it is important not to confuse the two distinctions; i.e. positivist versus interpretivist, ontology and epistemology on the one hand and between qualitative versus quantitative data analysis on the other. Jankowicz (2005) states that positivist approaches in the past have given importance to the quantitative methods while interpretivist approaches do argue for the importance of qualitative methods and techniques. However, both qualitative and quantitative techniques can be used even when a research is based on a purely interpretivist rationale (Shah and Corley, 2006). The present research is an inductive research, which studies the global gas-flaring scenario, and particularly in the Niger Delta region of Nigeria, with a view of finding a solution to the menace associated with the act of gas flaring. For this course, this research is adopted the qualitative research method which supports interpretivist philosophy as explained in the later stage of this chapter, specifically in Section 3.3.

3.2.3.2 Deductive Approach

Deductive research develops theories or hypotheses and then tests them out through empirical observation. It is essentially a technique for applying theories in the real world in order to test and assess their validity (Crowther and Lancaster, 2008). According to Saunders *et al.* (2009), deductive research can be quicker to complete, albeit that time must be devoted to setting up the study prior to data collection and analysis. In deductive research, it is possible to predict the time schedules accurately. Deductive research can be regarded as a lower risk strategy, notwithstanding there are risks involved such as non-return of questionnaires. Figure 3.3 is a schematic of the deductive research approach.

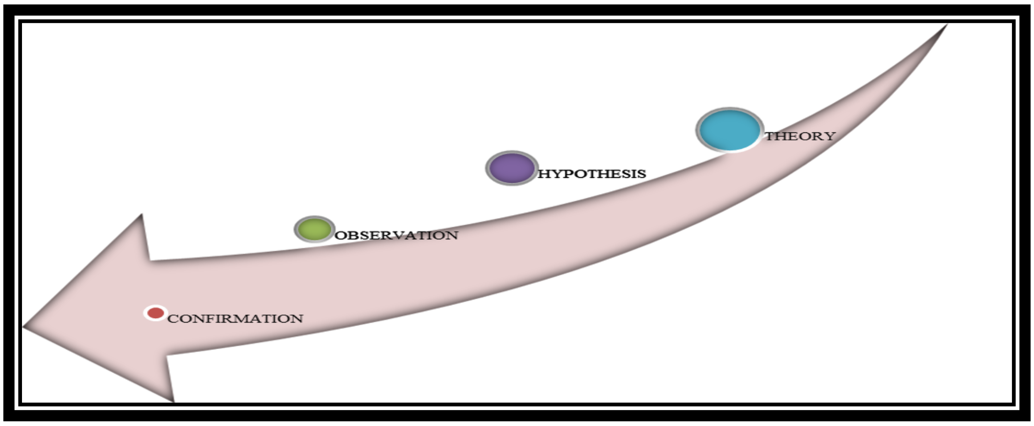

Figure 3. 3:Deductive research approach (Burney, 2008)

3.3 CHOSEN RESEARCH DESIGN FOR GAS FLARE MANAGEMENT

Creswell (2007) suggests the following characteristics as the contrast between the various qualitative approaches: the focus of the study; the type of problem to be answered; the discipline background; unit of analysis; data collection forms; data analysis strategies; the written report. These conditions help a researcher to choose the most appropriate qualitative approach for a study. In choosing between the qualitative approaches, Yin's guideline for the conditions and their appropriate research methods given in the table below followed (Yin, 2013).

Table 3. 2: Guidelines for the choice of Qualitative research approach (Yin, 2013)

Method	Form of research question	Requires control of behavioural events	Focuses on contemporary events
Experiment	How, why?	Yes	yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival records	Who, what, where, how many, how much?	No	Yes/no
History	How, why?	No	No
Case study	How, why?	No	yes

Based on the guidelines above, the inquiry into the reasons behind gas flaring, lack of utilization and possible means of utilization practices tend to align more with the question of 'what', 'how' and 'why'. In other words, 'why do oil and gas firms flare gas, and how could volume of flare gas be reduced sustainably? Combining the guidelines by Yin (2015) with the characteristics given by Creswell (2007), a case study approach is deemed the best for answering these questions. The nature of the question demands an in-depth description and analysis of multiple cases of oil and gas firms as well as electricity generation firms through the use of multiple sources of data. A case study research is appropriate for this phase of this study because the focus is on contemporary events.

3.3.1 CASE STUDY RESEARCH

The case study approach has been used previously in similar researches. Rahimpour *et al.*, (2012) used the case study approach to compare three different methods for gas flare recovery in a gas refinery; Mourad, Ghazi and Noureddine (2009) applied the case study approach in their research for recovery of flared gas through crude oil stabilization by a multi-staged separation with intermediate feed; and Tolulope (2004) also applied a case study approach in a research on oil exploration and environmental degradation in Nigeria. These researches proved to be successful through case study approaches; therefore, this study adopted the case study approach. The case study approach helped this study to investigate deeper into the operations in an oil and gas production and flaring organisation in the Niger Delta region of Nigeria. The study investigated the gas production, utilization and flaring activities. The study also investigated two organizations that utilize gas for the generation of electricity in Nigeria.

According to Yin (2013), the two main forms of case study research are single case studies and multiple case studies. Just like experiments, Yin suggests that the choice between single and multiple case studies depends on the problem being researched and the time available to the researcher. Single case studies are used with the objective of having an in-depth investigation into a phenomenon or concept to provide a rich description (Darke *et al.*, 1998; Yin, 2003) whereas multiple case studies are intended to enable theoretical replication (as used in multiple experiments) to ensure cross case analysis and comparisons (Darke *et al.*, 1998).

In adopting case studies as the research design, the main issue is to be able to determine the unit of analysis. In this regard, there is the added choice of having embedded or holistic units of analysis. Based on this, Yin (2013) describes four main types of case study designs: single case studies with holistic unit of analysis; single case studies with embedded units of analysis; multiple case studies with holistic units of analysis; and multiple case studies with embedded units of analysis. A summary of the various types are shown in Figure 3.4 below.

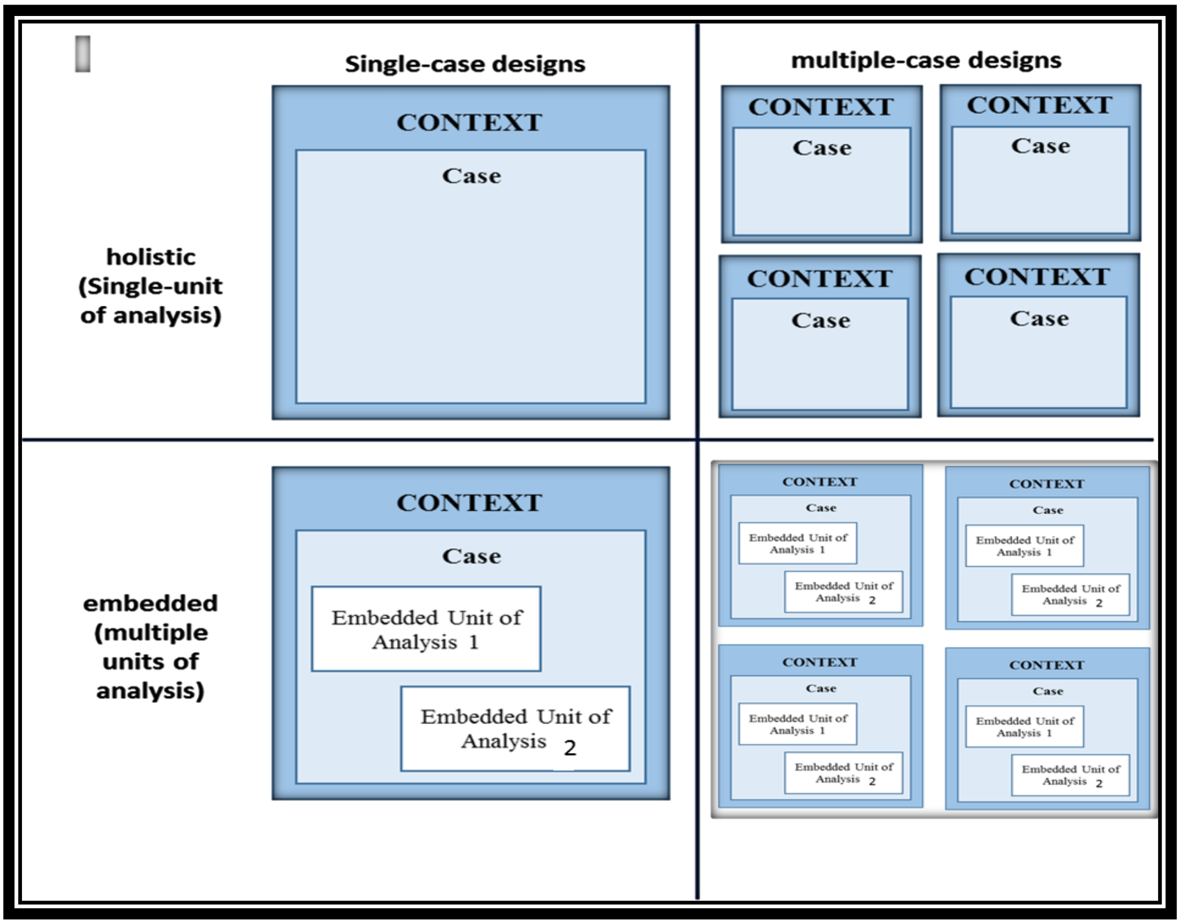

Figure 3. 4: Types of Case Study (Yin, 2013)

From the Figure above, this research adopted a case study approach with embedded units of analysis. The advantage of this approach is to help capture different companies who undertake activities relating to gas utilization and management, which has gas flaring as part of the process. Three companies were used for the study and have been accordingly classified as Case Study Company 1 (CS1), Case Study Company 2 (CS2) and, Case Study Company 3 (CS3). Data collections in these case companies are carried out using interviews, organizational documentary analysis and, observations. The above-stated have been elaborated in more details in Sections 4.2, 4.3, and 4.4. More so, specific details concerning the CS1, CS2 and CS3 are demonstrated in Chapter Four of this thesis. These cases guided the research to identify the remote causes/reasons for gas flaring in Nigeria, as well as providing core awareness towards the electricity generation and distribution scenarios in Nigeria. Figure 3.5 shows schematics, which highlight the research design of this study, and clearly identifies the three fundamental stages – study, methodology, and analysis and results. This has been explained in greater details earlier in Section 1.6.

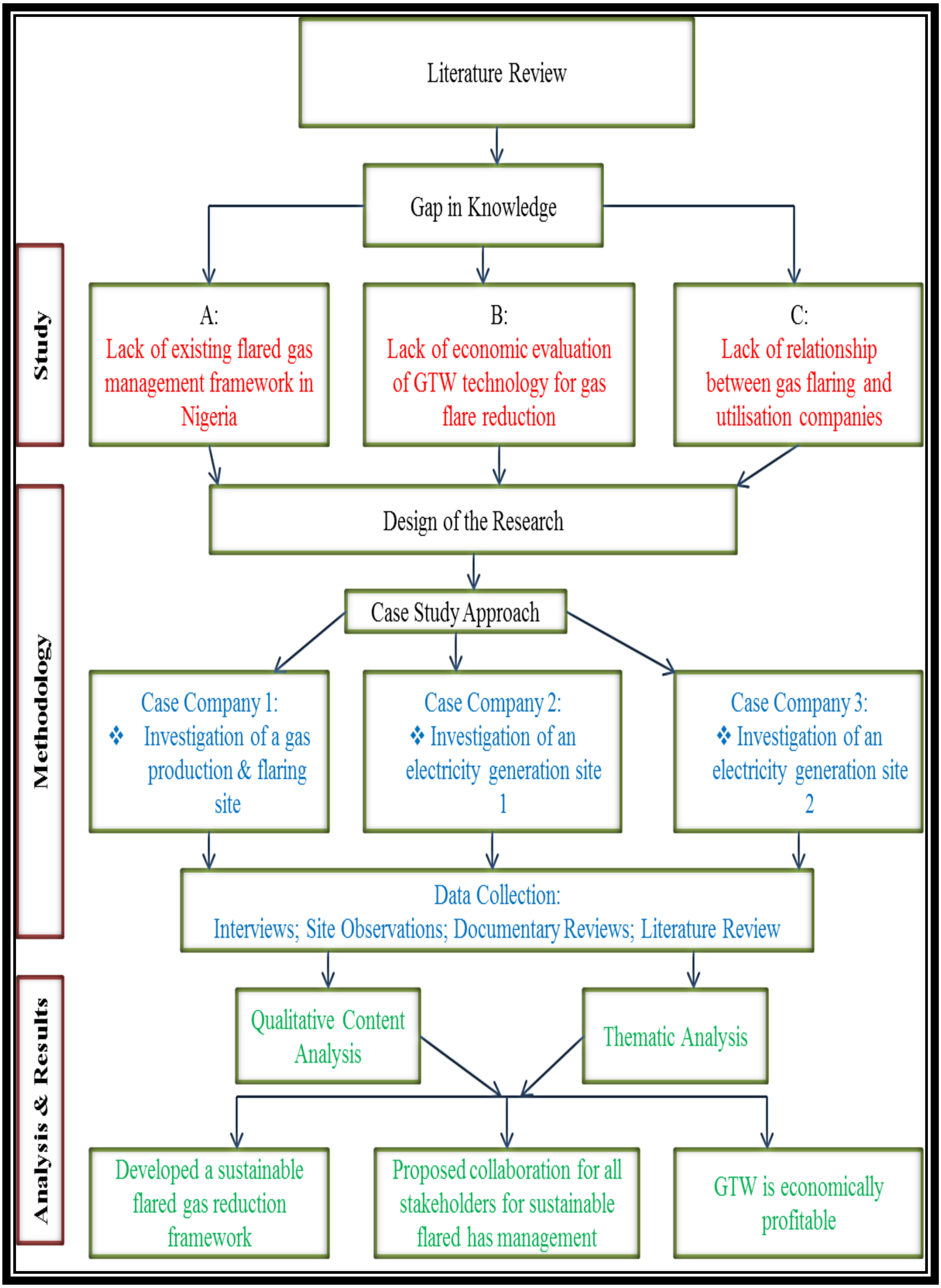

Figure 3. 5: Schematics of the research design showing start to finish of research

3.4 Data Collection

The study applied two basic approaches, but with three distinct ways in the collection of data. Firstly, through review of relevant literatures on gas flaring. The study also reviewed vital literatures on electricity production with more emphasis on gas turbine and its thermodynamics. Secondly, the study applied the use of case study. Interviews were conducted with participants from the three companies who had the relevant experiences and knowledge of gas management and gas flaring, as well as electricity generation. These included professionals from one oil and gas producing organisation and two electricity-producing companies. In line with this, the study also collected raw data through documentation and observation

In clearer terms, three sources of data collection methods were applied in the case study, and they include interviews, documentation, and observation. However, it is worth noting that the specific data collection methods for a given research is dependent on the nature of the research, expectation of the research, as well as successive usage of such data.

3.4.1 Literature Review

Literature review as a data collection method was utilized in this research to provide an academic understanding before the empirical study. According to Anderson and McAdam (2004), this provides the study with an opportunity to effectively review existing studies related to the research problem, as well as the identification of the significant issues and concepts. Furthermore, literature review is used for the identification of possible and relevant gaps in existing literature in the area of study, thereby providing a proper focus for the researcher. Review of literature also helped this research to tackle and achieve some of the research objectives.

This study systematically reviewed previous literature on global gas flaring to understand the concept and reasons behind gas flaring as well as the major countries involved in the act. This also helped the study to understand the various adverse effects that are associated with gas flaring such as environmental, economic, health and safety impacts. Furthermore, specific gas flaring countries were studied with regards to existing gas flaring regulations, policies, permissions, restrictions, enforcement, monitoring and penalties. A review was also carried out on the existing gas flare management technologies.

Review of existing literature was also carried out on the gas flaring situation in the Niger Delta region of Nigeria. This provided the researcher the opportunity to investigate deeper into the

Nigerian scenario. Specific participants in the Nigerian oil and gas industry were identified, and their level of involvement in gas flaring was highlighted. The literature review helped the study to understand the issues surrounding gas flaring and to identify gaps in gas flare management.

Review of literature was also carried out on gas turbines. The review included the thermal efficiency of turbines, where it was recognized that temperature and pressure affects the efficiency of a turbine. In other words, higher pressure and temperature lead to higher thermal efficiency.

Literature review was sourced from scientific Journals like International Journal of Emerging Trends in Engineering Development, Journal of Natural Gas Science and Engineering, Energy Journal, Journal of Natural Gas Science and Engineering. Data was also obtained from relevant textbooks, as well as from trusted organizational and private websites.

From the literature review, the study identified three major gaps in knowledge which were used as points of focus and drive towards providing solution. These gaps included the following:

1. Lack of existing flared gas management framework in Nigeria.
2. Lack of economic evaluation of GTW technology for gas flare reduction.
3. Lack of cordial relationship and understanding between oil and gas producing/flaring companies and electricity producing sector for flare gas management.

3.4.2 Interview

According to Putnis and Petelin (1996), interview is an important form of communication in a society. It is a means of exchange of information between individuals for the purpose of achieving successful communication. Although interviews are essentially an exchange of information, nonetheless Dwyer (1993) distinguishes interviews from casual conversations on the basis that interviews are planned, prearranged, structured, controlled by the interviewer, have a predetermined purpose and take place between two or more people of different statuses. Marshall and Rossman (1999) suggest that when research has an exploratory focus, just as this research, the appropriate research strategies should be field studies comprising in-depth interviews. Interview is an opportunity for drawing on the knowledge of the practitioners without posing a bias as people were able to talk about something in detail and in-depth.

This study used interviews to obtain, through exchanges, in-depth and diverse meanings of a phenomenon from the interviewee’s experience. Three companies were involved in the interview process namely CS-1, CS-2, and CS-3. We identified and carried out interviews on five (5) key personnel within each organisation. The choice of these interviewees was based on the fact that the study intends to use the results from the interview as part of a guide to develop a framework for gas flare management, therefore the following key position with responsibilities were chosen and interviewed as follows:

For CS-1, the study interviewed the production manager, health and safety manager, operation supervisor, and 2 field operators.

For CS-2, the study interviewed power plant operator, operations and maintenance manager, electrical maintenance repairer, technical manager, and shift supervisor.

For CS-3, the study interviewed power plant operator, operations and maintenance manager, electrical maintenance repairer, technical manager, and shift supervisor.

In this study, a semi-structured interview was carried out within the three case studies. This technique is also known as open-ended interview. Using semi-structured interviews was more flexible and allowed for the exploration of emergent themes and ideas in this study. A digital voice recorder known as TASCAM DR-05V2 was utilized for the audio recording during the interview sections. This particular recorder was used mostly because it has a USB slot, which supported me to slot in an external memory of 20GB memory slot, and also due to the fact that it captures uncompressed audio in Audio Interchange File Format (AIFF) which supports maintaining my original recording quality.

Interviews in this research were designed using standard best practice guidelines (Serpell and Rodriguez, 2002) and in this study, the targeted interviewees were the experienced key project participants. It emphasizes on understanding the meaning of the interviewee’s experiences regarding the phenomenon under study (Gubrium and Holstein, 2002). It is open-ended in nature and focuses on the variety of meanings that emerge from conversation between the interviewer and the interviewee. Techniques for semi-structured or open-ended interviewing vary. Patton (1990) identifies three different approaches or techniques. These are the informal conversational interview, the general interview guide approach and the standardised open-ended interview. These approaches do not only differ in terms of the preparation required but also in terms of conceptualisation and instrumentation (Patton, 1990, p.280). In the case of conversational interviews, questions are generated as the interaction between the interviewer and the interviewee progresses. There are no pre-determined questions. The second interview technique described by Patton (1990) is the standardised open-ended questions. With this approach, carefully worded set of questions pre-arranged in a particular order is administered to all interviewees in the same way. The advantage of this approach is that variation in questions asked is minimized. The third interview technique is the general interview guide approach. Patton (1990, p.280) described this interview approach as entailing the following features:

i. Outlining a set of issues to be explored prior to the interview
ii. Issues in the outline need not be dealt with within any particular order
iii. Actual wording of questions used to elicit responses about the issues need not be pre-determined.
iv. Interview guide simply serve as a basic checklist to ensure that all relevant topics are covered
v. The interviewer adapts both the wording and the sequencing of questions to specific interviewees in the context of the actual interview.

The advantage of this interviewing technique is that it allows interviewers to cover relevant topics and at the same time offers the flexibility to probe and ask follow-on questions in relation to specific topics. Additionally, the interviews followed a basic structure of open-ended questions formats and schedules, which served as the interview guide as shown in Appendixes A and B

To make sure that the rightful interviewee are selected and chosen to be able to extract the needed and useful information or data for this study, we chose mostly the top ranking members of staff from the oil and gas producing and flaring organisation. This is because the aim of the research is to develop a framework that could manage and minimize gas flaring in the oil and gas sector, in order to reduce waste and minimize associated environmental impacts, and thereby improve the economy. To achieve this, it was imperative to get the ideas of the top managers and experienced members of staff. The same applied to the electricity-producing organisation – top ranking members of staff and experience members of staff were chosen because this study needed to understand the intrigues in electricity production, distribution and management, as well as the importance of gas in electricity generation in a gas-fired power plant.

The interviews carried out on members of staff from the Oil and Gas Company supported this study in achieving objectives number 2 and 5 as stated in Section 1.5 of this thesis. The interviews on members of staff from the electricity generation companies supported the study to achieve objectives 4 and 5.

3.4.3 Documentation

Creswell (2009) provided three advantages of documentary analysis. Firstly, they carry the language and words of the authors thoughtfully assembled. Secondly, they are unobtrusive source of information capable of being accessed and reviewed at any time. Finally, they save the researcher time for transcription. Though useful as data source, documents may sometimes be inherently biased because they may be prepared for specific events and may not carry a complete picture of the phenomenon they address (Yin, 2009). There is also the challenge of accessibility of relevant documents due to confidentiality (Creswell, 2009). To this effect, some documents that were tagged ‘highly confidential’ by the organizations were systematically deprived from the researcher. Although it is also worth mentioning that this singular act did not negatively affect the importance of use of documentation as a way of data collection in this research.

In case study Company 2, most of the documents were in paper forms. In other words, the organisation does not have an electronic database for its documents. This therefore, posed as a challenge towards accessing some official documents. From case study company 2, some of the documentary evidences obtained included reports for plant inspection, report for equipment status and report for staff strength. However, in case study companies 1 and 3, the organizations had partial availability of electronic document, which proved useful for this research. Documentation was used to form the basis for understanding the background of the case study companies, the roles of the senior personnel and the workflows within the company.

Furthermore, information on some of the documents was used to confirm the evidence gathered from other sources like the internet and academic journal papers. The review of some company’s documents enabled this study to probe further in order to confirm some details like volume of gas flare and gas production in Nigeria, thereby avoiding contradictions. Inferences were also gathered from documents, which at a later stage served as suggestions for further investigation. Documents read during the researcher’s stay in the companies typically included memoranda, agendas, minutes of meetings, progress reports, administrative documents and newspaper articles. This provided further evidence to other data collected via interviews and surveys, despite the fact that Yin (2012) stated that researchers must not regard documents and records as a pure account of facts that have happened. However, Myer (2001) stated that the use of documents is important because they can be used as inputs to the interview guide and used to identify statements made by key people in an organisation. The use of documents can also be helpful in counteracting biases from interviews. Analysis of the documents assisted in the understanding of the reactions and feelings captured in the survey and interviews, ensuring results were placed in the right context (Sapsford and Jupp, 2006). The analyses of documents and records help to examine the validity of information obtained by other methods and can also provide further information on issues that the researcher is interested in gathering. The documents were analysed bearing in mind the aim of the research. This was done by carefully reading the documents in order to understand the general focus for each of them. Afterwards, the researcher focused on key information that was relevant to the present research and then incorporated that information in the report since the major reason for reviewing the documents was to back up facts already obtained from the interviews.

3.4.4 Site Observation

In general terms, observation is a method that involves viewing what people do, listening to what they say and at times asking them questions to simplify certain issues within the site. However, Stake (1995) and Gillham (2000) further identify the benefits of engaging in observation which include looking at what people actually do, rather than what they say that they do, or why and how they should be doing it. In the oil and gas-producing organisation, data were captured by carefully observing the various activities like witnessing the process of gas flaring directly from the flare stack. Also while in the electricity power station, observations were made to identify and distinguish the functional gas turbines from the non-functional gas turbines, as well as identifying the decommissioned gas turbines. This helped to validate the information this study acquired through interviews. Field notes were written in the process and further compared with the information provided by the participants during the interviews.

Observations were carried out in case study companies 1, 2, and 3, where the operations of the activities in the site were witnessed; the working conditions of the equipment like gas turbines and supply of gas were also observed, as well as gas production, utilization and flaring from the sites. Data collected through this means was documented through photographs and field notes as recorded by the researcher.

In general terms, the observation process during the studies entailed both participant and non-participant observation. It is worthy to mention that this study indulged mostly in the non-participant observation, although there was also a little bit of direct participatory involvement. During the participant observation, the researcher systematically observed and also got involved with some members of staff like some technicians and enquired to find out the causes of non-functionality or decommissioning of the gas turbines in the power stations; while in the non-participant observation, the researcher observes the behaviour of people in the site from a distance without any form of direct interaction with the process of gas flaring or electricity generation.

The non-participant observation was noted to be an important process of an action research as the researcher was expected to capture what would likely not have been explicitly recorded in any documentation. Although, Yin (1994) argues that there is the risk of the presence of the researcher influencing the events being monitored.

With regards to the participant observation, the researcher also observed the planning as well as actions in the organization, however, the researcher questioned some employees in the organizations, especially the leaders or managers of departments. During both the participant and non-participant observations, the researcher was able to understand the culture, behaviour and intentions of the project participants.

3.4.5 Economic Analysis of Gas-to-Wire

From the empirical data collected from the case study (CS-1, CS-2 and CS-3), the study went further to carry out a cost and effect analysis of using GTW technology as a tool for the management of gas flaring. These calculations were done based on a gas turbine sample (ALSTOM GT13E2) with 150 MW capacity. Some assumptions and factors were put into consideration for this analysis and they include the following:

1. The economic evaluation is based on the assumption that the availability and consistency of the gas turbine (in terms of being in good working condition) is 100% throughout the year (i.e., the plants operate for 365 days of the year).
2. We further assumed that the units of gas turbine operate at full power capacity, which is 150 MW, and selling all the produced electricity to the national grid.
3. It is also worthy to reiterate that this economic assessment is based on 50 units of gas turbine.

Calculation were based on break-even point capacity (B.E.P), product cost for plant, yearly income in B.E.P capacity, total yearly income, gross profit, net profit and rate of return of investment (ROI). It is worth mentioning that the equations used for these calculations were adapted from Peter and Timmerhaus (1991). This helped this study to achieve objective 4 and 5 as stated in section 1.5 of this thesis.

Figure 3.6 below demonstrates a schematic link between various research methods used in this study and the accomplishment of the research objectives.

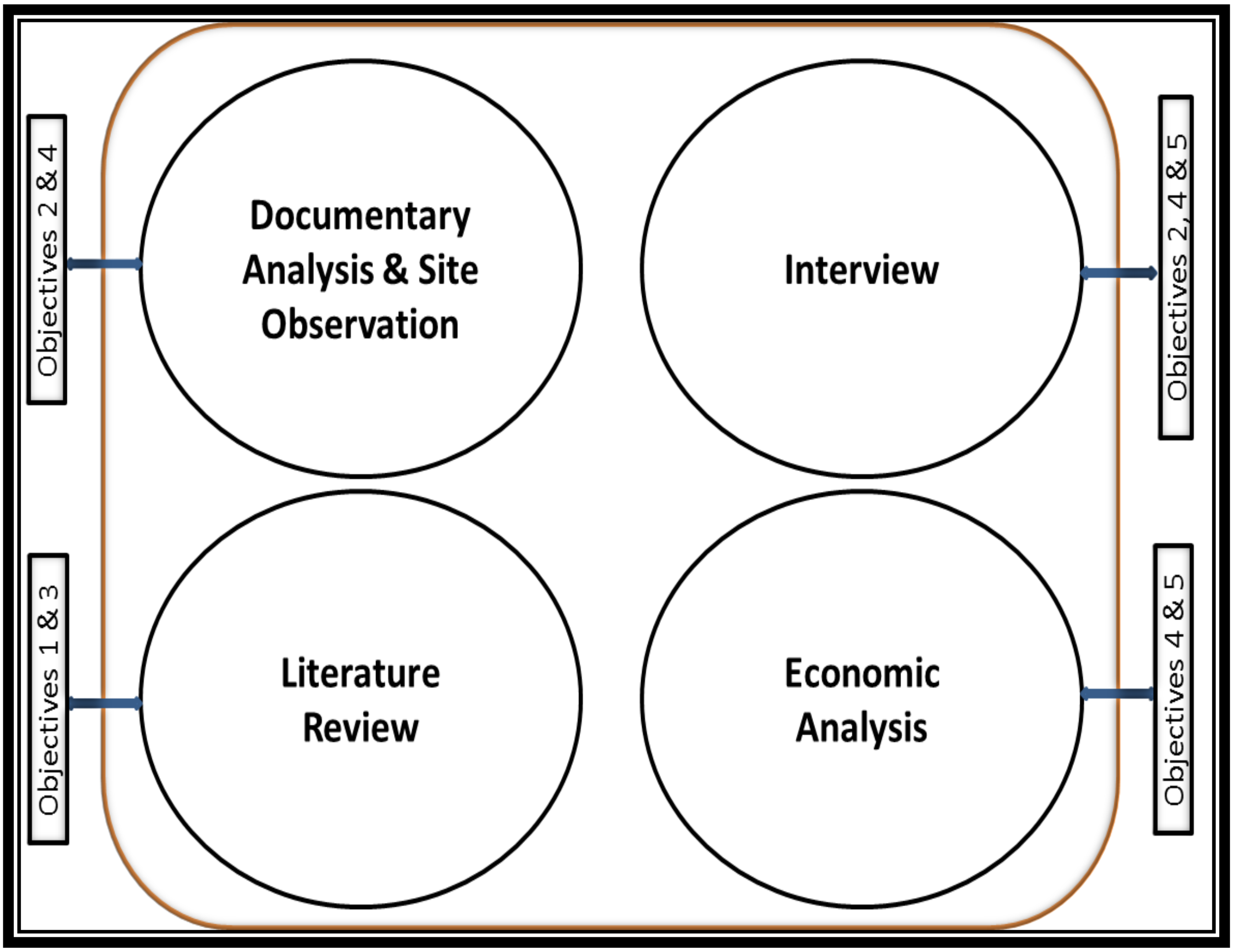

Figure 3. 6: Relationships between Research Methods and Research Objectives Achievement.

3.5 DATA ANALYSIS

To obtain an answer to the research questions and authenticate the central argument of the research, there is a need to explain and find meaning to the collected data. It is, however, difficult to explain raw data, therefore the need for analysis and interpretation. This requires the data to be categorised, ordered, manipulated and summarised into intelligible and interpretable forms in order to study the relationship between the research variables, and address the research questions (Kerlinger and Lee, 2000).

This study collected qualitative data through interviews, documentary analysis and site observation; therefore there is need to carry a qualitative analysis. This form of data analysis and how it was carried out in this study has been described in the successive sections.

3.5.1 Analysis of Qualitative Data

Qualitative data analysis essentially involves taking the data apart, understanding the components and how they relate to each other (Stake, 1995). Miles and Huberman (1994) summed up the idea of qualitative data analysis in the following words: 'to review a set of field notes, transcribed or synthesized, and to dissect them meaningfully, while keeping the relations between the parts intact, is the stuff of analysis'. Creswell (2009) contends that regardless of the type of qualitative methodology employed, a common process to qualitative data analysis involving six steps is discernible, though the steps may not necessarily be linear. These are as follows:

(a) Organization and preparation of data for analysis (including transcribing interview data, typing field notes, scanning documents and other visual images)
(b) Reading through the data over and over again to get the general sense of the data
(c) Coding (segregating data into chunks)
(d) Using the coding process to identify categories or themes and also to generate description
(e) Contextualizing and finding linkages between the themes to identify how they fit together in the narrative
(f) Interpretation-making meaning of the data. Qualitative data analysis methods commonly employed by researchers using different qualitative research methodologies include thematic analysis and qualitative content analysis.

These steps that have been stated above guided this research to finding some specific incidences in the case study companies that were studied, for instance it helped the research to identify specific volume of gas produced, utilized and flared in a typical gas plant in Nigeria. More so, the amount of electricity generated within a given power station was identified and it also highlighted the importance of availability of gas or lack of it towards electricity generation.

Figure 3.7 is used to demonstrate processes applied towards analyzing the data collected for this study. To analyse these data, the study applied the use of a software known as NVIVO (NVIVO version10). With the help of NVIVO, the thematic analysis and content analysis were chosen as the forms of analysis for the data collected. Bryman (2008) describe thematic analysis as entailing 'searching-out of the underlying themes in the materials being analysed.' In this sense, this method of data analysis can be distinguished from quantitative content analysis, which places emphasis on word frequency count (Stemler, 2001). Hsieh and Shannon (2005) also defined thematic analysis as 'a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns'. Thematic analysis emphasizes pinpointing, examining, and recording patterns within data. Themes are simply the patterns across data sets that are important to the description of an occurrence and could be associated to a specific research question. Content analysis is a method of analysing written, verbal or visual communication messages (Cole 1988). It is also known as a method of analysing documents. Subsequently, according to Krippendorff (1980), it is a research method for making replicable and valid inferences from data to their context, with the purpose of providing knowledge, new insights, a representation of facts and a practical guide to action. This helped this study to broadly describe the phenomenon of gas flaring; and was vital towards building categories.

Furthermore, Within-case analysis was further applied. This form of analysis supported this study to analyse each case study company solely, to determine the interrelationships between different themes of findings from the data. This was carried out on all three case study companies – CS-1, CS-2 and CS-3. After the within-case analysis, this study carried out a cross case analysis, whereby an analysis was done on all the case studies through the process of comparison. This was carried out to identify similarities and difference among the case study companies. For instance CS-2 and CS-3 are organizations from the electricity generation sector: so a cross case analysis highlighted use of gas for electricity generation, and also showed that CS-2 is associated with lot of non-functional gas turbines due to lack of maintenance and fund; while CS-3 is devoid of such, especially non-functional turbines.

These methods were chosen because they are similar in the sense that they emphasis on the identification and development of themes. Bryman (2008) stated that a closer examination of the qualitative data analysis methods discussed above shows that generally, they all share common techniques and approaches to data analysis. Nevertheless, Creswell (2009) acknowledges that in addition to the common qualitative data analysis methods there are specific data analysis procedures, which are primarily associated with particular methodologies. For instance, Yin (2009) recommends five analytical techniques for case study analysis namely pattern-matching (comparing an empirically-based pattern with a predicted one with the aim of developing theoretically significant explanation for the outcome), explanation building, time-series analysis, logic frameworks and cross-case synthesis. Ethnographers employ thick description and theme development whilst phenomenologists focus on generating meaning from data. And as stated earlier, the study utilised both thematic and within-case analysis.

Principles and tools for data analysis used in the analysis of the qualitative data include coding, constant comparison, questioning, diagramming and memoing. Glaser (1978) and Glaser and Holton (2004) identify three data coding phases namely open/substantive, selective and theoretical coding. Substantive coding refers to the process of conceptualizing data in the empirical state (Glaser and Holton, 2004). This is an intensive line-by-line coding which generates concepts closely related to the data. Theoretical coding refers to a 'second-order' coding, which determines how the substantive codes may relate to each other (Glaser and Holton, 2004). Strauss and Corbin (1998) maintain an elaborate three-phased coding system namely open, axial and selective coding. Open coding is the researcher's first analytical commitment with the data, which results in breaking down of data into chunks. Incidents, events/actions and interactions are compared with others for both similarities and differences. Conceptual labels are then assigned. Further, the dimensions and properties of these conceptual labels are explored.

In this research, the data analysis began after all interview data as well as documents collected had been imported into the qualitative data analysis software NVivo. Coding began by giving terms and keywords relevant to this research such as gas flaring, factors influencing gas flaring, flare management, and influencing factors. In total, about 78 codes were identified during the initial coding process. The second level of coding, axial coding, followed where the various terms and codes were combined to create sub-themes and categories. As part of axial coding, a connection was made between categories and their sub-categories and the ensuing relationships are tested with data through coding of conditions, actions /interactions and consequences. The coding process is described by Strauss and Corbin (1998) as a process, which helps in systematic analysis of the data so as to enhance integration between structure and process. The idea behind axial coding was to re-assemble the data broken up during open coding in a more meaningful and logical way. With selective coding, all other categories are reconnected to a core category. Throughout the process, the codes and categories were grouped to form themes based on the aims of this research.

Data analysis also involved constant comparison, which deals with the part of the analytical process where different pieces of data are compared for differences and similarities. Glaser and Holton (2004) identify three types of comparisons namely:

(a) Incident to incident
(b) Concepts to more incidents
(c) Concept to concepts.

The aim of the first type is to generate concepts. The second type aims at achieving theoretical elaboration. Concept-to-concept comparison aims at integrating concepts into hypotheses, which eventually culminate in the development of a theory. Corbin and Strauss (2008) refer to two types of comparisons namely incident to incident and theoretical comparison. The latter is a comparison at the level of properties and dimensions and helps the researcher to think in terms of abstracts.

The coding process helped to extract thoughts, ideas, analysis and notes concerning gas production, utilisation and flaring in memos from the data collected. This captured other areas such as electricity generation. At the end of the analysis process, major themes that emerged from the process include: gas production and utilization; gas flaring; reasons for gas flaring; and gas flare management for case study one. For case studies 2 and 3 which were electricity production companies, the main themes include: electricity production; sources of gas for gas turbine; typical problems in the power station; general plant condition and maintenance; volumes of gas utilization in power station; and strategies to improve gas utilization. These themes formed the basis for presenting results of the case studies. As earlier stated, a schematic of the data analysis processes in this study is shown in Figure 3.7

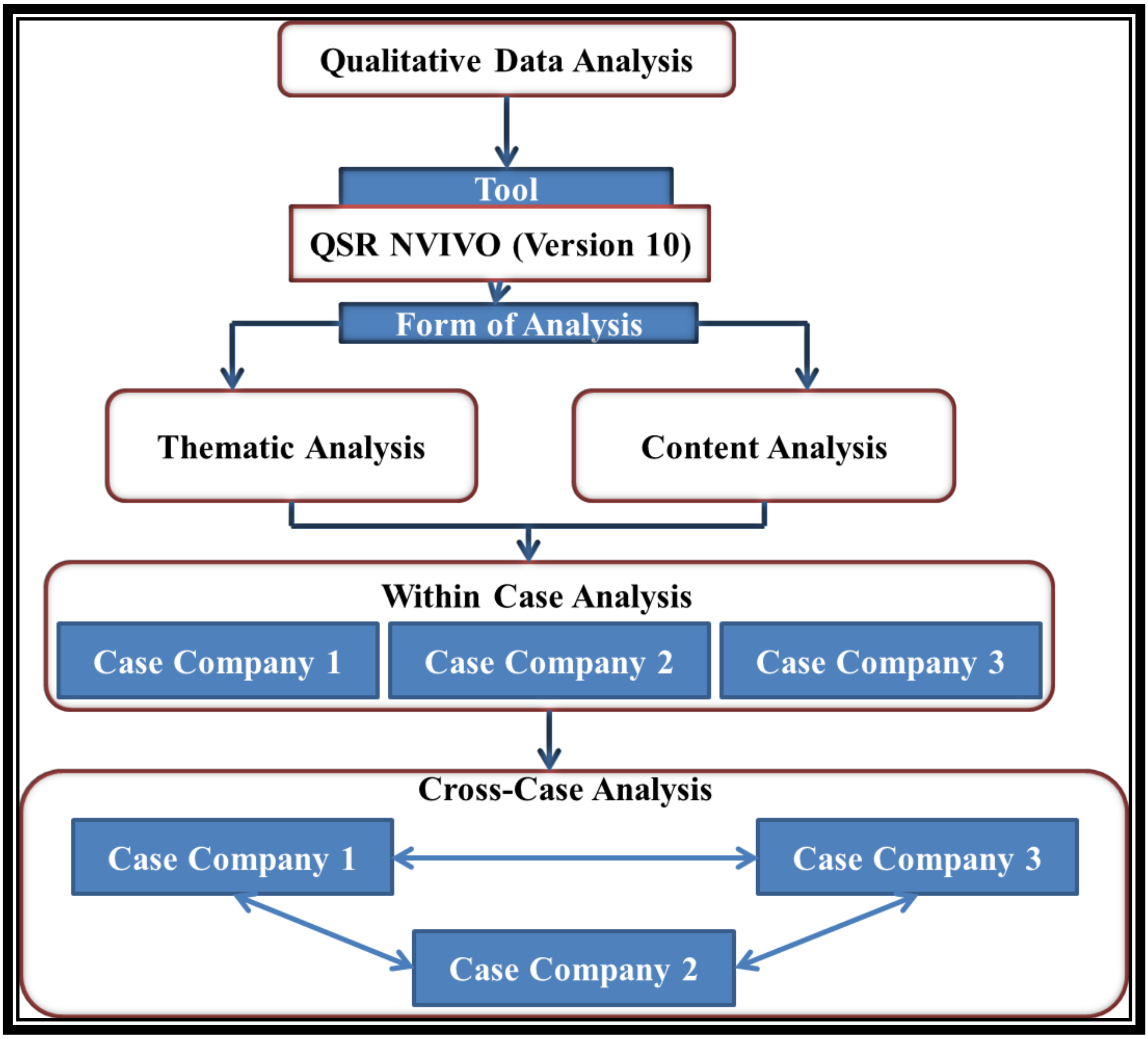

Figure 3. 7: Data analysis process.

The output from this analytical process is presented in Chapter 4 of this thesis based on the themes developed. Notable themes developed included themes on: gas management; gas flaring; factors leading to gas flaring; and measures in place to control gas flaring.

3.6 FORMATION OF TREE NODES

The research analysis process began with the coding of the data received from the research using the NVIVO software (See 3.5.1). From the formation of nodes through the coding process, the 178 nodes created were further grouped based on similarities in the messages they carried to form tree nodes. These nodes represented ideas that could be put together to form main areas to be discussed in the research. An example of some of the tree nodes produced through this analysis process is shown in Figures 3.8 and 3.9 below.

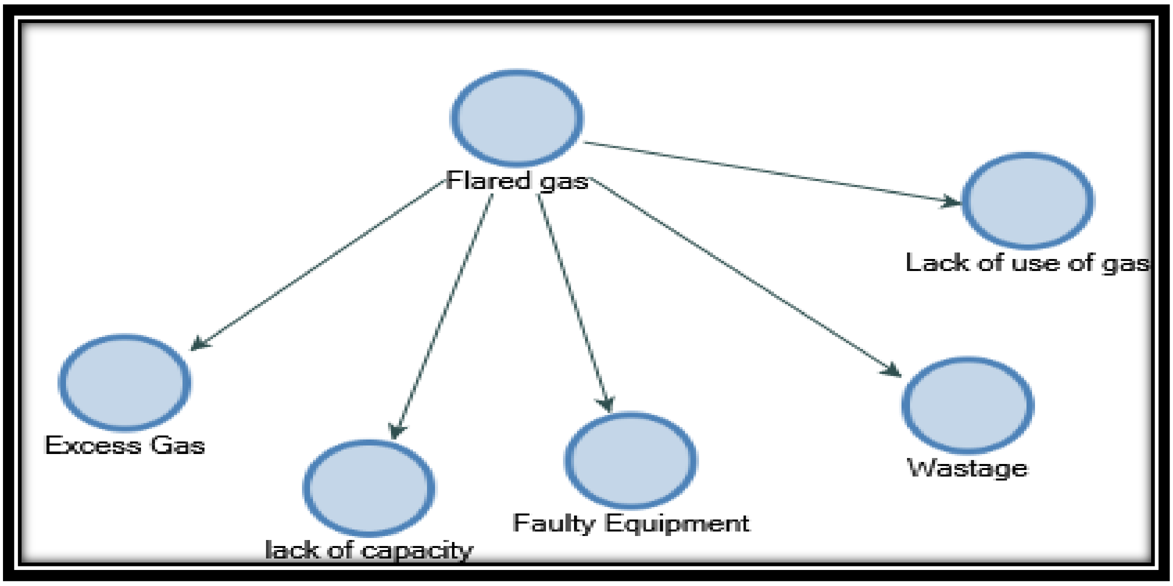

Figure 3. 8: Typical Tree Nodes Created from Flared Gas

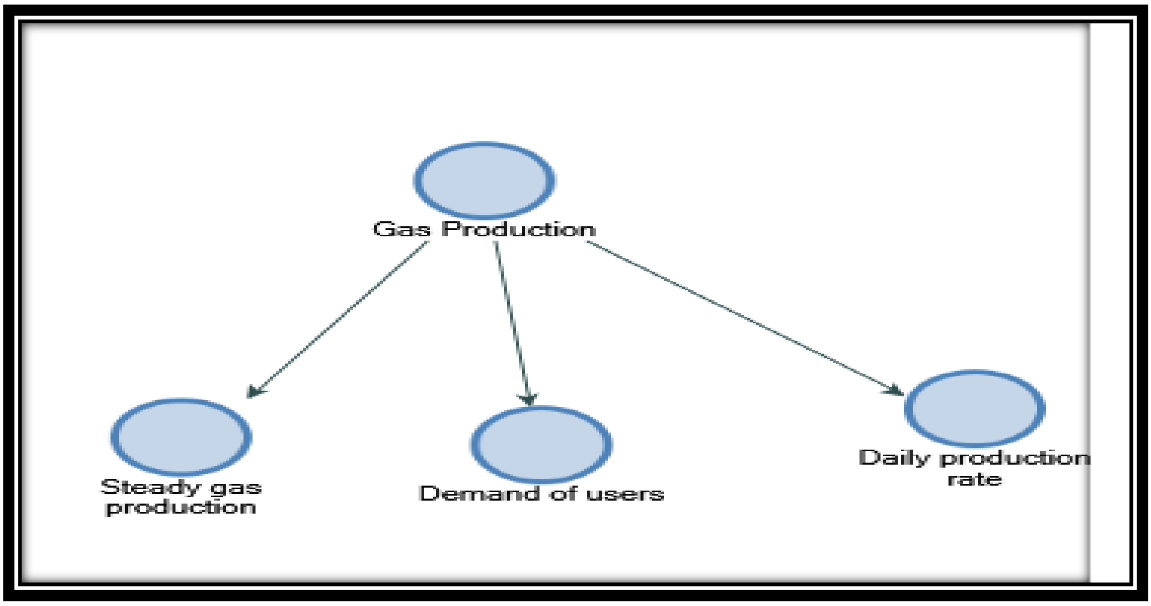

Figure 3. 9:Typical Tree Nodes Created from Gas Production

As seen from the Figures above, codes/nodes that relate to similar ideas are put together to make more meaning as codes on their own do not add a lot of meaning to the research. From this process, about 50 tree nodes were created. The need to ensure the analysis process resulted in the themes that to be discussed in line with the aim of the research, the tree nodes were further grouped into the formation of categories. From the Figures, gas production as a tree node was created from the issues affecting gas production such as daily production rate of the companies and this was based on the demand of user and the need to ensure steady gas production. Another example is the formation of tree node for flared gas. As seen from the Figure, it was identified through the analytical process that issues such as faulty equipment, excess gas due to lack of capacity, and wastage were the reasons leading to increased flared gas.

These nodes were further developed into categories which were then developed into themes and sub themes as detailed in Chapter 4 of this thesis (See Section 4.2 and Figures 4.1, 4.2, 4.3, and 4.4).

3.7 ETHICAL CONSIDERATION

There is no doubt that the idea of a research is to, among others, test theories, make inferences and add or updates knowledge (Frankfort-Nachmias and Nachmias, 1996; Kerlinger and Lee, 2000). However, in undertaking researches, researchers must be guided by some form of ethics (Shrader-Frechette, 1994). Shrader-Frechette (1994) emphasizes that research ethics specify conducts that researchers ought to demonstrate during an entire process of research.

Thereby in line with conducting this research, ethical issues were considered to be of high priority because human participants are treated as collaborators rather than as subjects, (Bailey, 2007). Hence, it was considered throughout the research process, from the case designs, to the selection of data collection methods, and throughout the implementation processes. The whole research was conducted in a way that ensured that confidentiality and integrity of the participants were respected. The researcher dedicated great effort to maximizing the research benefits and the reduction of research risks that might occur from the research. Hence particular concerns were given to the participants of the case studies. They were informed of the research aim and objectives and the consent was sort to participate on voluntary basis. Critical reflections on ethical aspects of the case studies were done prior to conducting any field study. Similarly, an ethical approval form was submitted to the ethics committee at the University of Wolverhampton as shown in Appendix F, and approvals were obtained in June 2013. Furthermore, participants were guaranteed that all information would be handled with strict confidence and anonymity. The participants, particularly the interviewees were made to understand that they were free to opt out from the process at any point of the interview.

3.8 CHAPTER SUMMARY

This chapter created an in-depth explanation of the research method used for the purpose of this research and a justification for the choice of the research method chosen. It is also worth noting that the research strategy for this study was based on the nature of the data collected. The research employed qualitative research method, which entails the use of multiple case studies. This is due to the aim and objectives of the study.

Therefore, this research applied an interpretivist philosophy. Subsequently, a case study approach with embedded units of analysis was applied, whereby data were collected through interviews, documentary analysis and site observation. Data were collected from respondents across a wide range of respondents within the oil and gas and electricity production environs in the Niger Delta region of Nigeria. As prescribed by Patton (1990), these data collection methods are concise and are capable of providing the necessary information needed for research outcome, if done correctly.

For data analysis, the content analysis is applied in this study. These analytical methods provided more clarifications pertaining to gas flaring such as volume of gas flaring, gas utilization as well as some remote causes and reasons for continual gas flaring. Finally, ethical concerns with regards to data collection were discussed and treated.

CHAPTER FOUR: DATA PRESENTATION AND ANALYSES

4.1 INTRODUCTION

This study adopted a case study approach to collect qualitative data from oil and gas producing as well as electricity producing companies in the study area. The essence of the case study approach is to identify the key issues leading to gas flaring and its management. Three companies were used and included one Oil and Gas Company and as such experiencing gas flaring. The two other companies are into electricity generation. The essence of using the electricity generation companies is in line with the aim of the study to propose GTW as a technology for management of flared gas. The study on the electric companies therefore help to understand the processes the companies go through and any inherent problems they face. Two electricity-generating companies were used for the purposes of replication, to ensure the results were fairly consistent. This chapter analyses and discusses the results from the case studies and begins with a background of the companies used. However, prior to the data presentation and proper analysis, the process for formation of the categories and sub-themes formations are explained in the immediate succeeding Section.

4.2 FORMATION OF CATEGORIES AND THEMES/SUB-THEMES IN DATA PRESENTATION PROCESS

4.2.1.1 Formation of Categories

In forming categories, the tree nodes that were discussed in Chapter 3 (Section 3.6) were further reviewed by analyzing the information they coded to identify nodes, which were closer in the areas they covered. These were then put together to make categories which covered major areas to be discussed by the research. Categories gave the researcher the chance to pause and think about the aim of the research and how the main ideas could be carried forward leading to conclusions that represent the data gathered. The categories shaped the outcome of the research further leading to the creation of the main themes of the research. Examples of the categories and sub-themes are displayed in Figures 4.1 and 4.2 below.

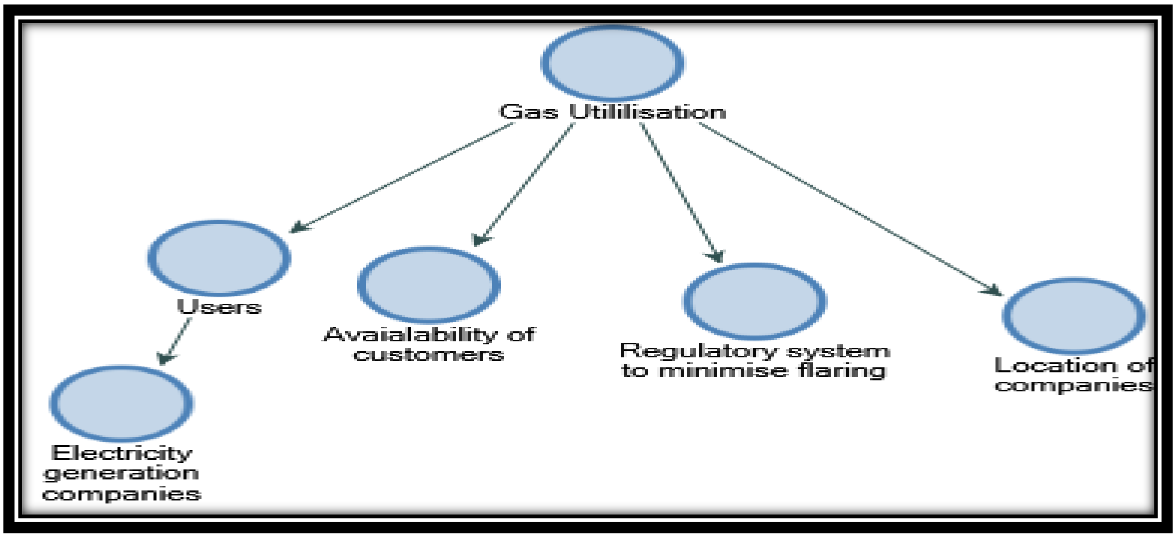

Figure 4. 1: Category for Gas Utilisation

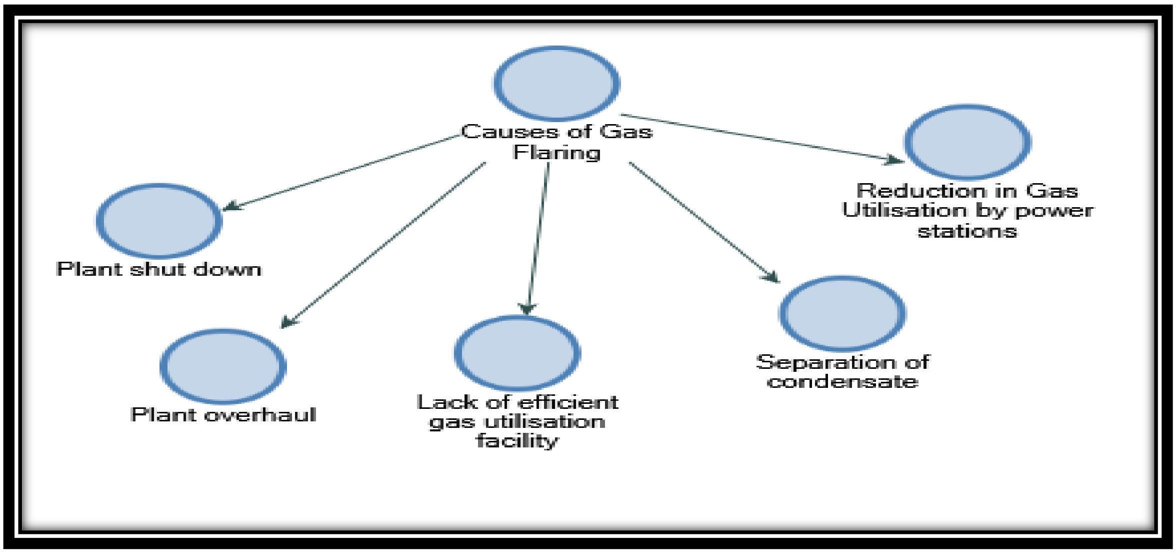

Figure 4. 2: Theme for Causes of Gas Flaring

As seen from Figure 4.1, the category for gas utilization was created based on the factors influencing the utilization of gas in the companies and this was identified to be based on the location of the companies, the regulatory systems in place, the availability of customers, and the users of the gas which were mainly electricity generation companies. Causes of gas flaring as a theme were also created based on the factors identified from the analysis of the data (as shown above in Figure 4.2).

4.2.1.2 Formation of Sub-Themes and Themes

From the categories formed, the next step in the analysis process was to create themes which formed the main basis for discussing the outcome of the research. Two main themes were created for presenting the results of the research and these are gas production and utilisation; and gas flaring. These themes were further broken down into sub themes, which helped with the better management of the results of the research. These sub-themes included: views of respondents on gas management and flaring; issues leading to gas flaring; problems with gas flaring; plant conditions in the companies; strategies for improvement of activities of the companies; and gas to wire technologies.

These themes and sub themes formed the basis for presenting the results of this research in the next chapter. The presentation of themes and sub-themes in the within case analysis helps to analyse the results by comparing the companies to identify the common grounds and results as well as differences. A typical example is shown in Figure 4.3, which highlights a theme (Gas Flare Management) with subsequent categories.

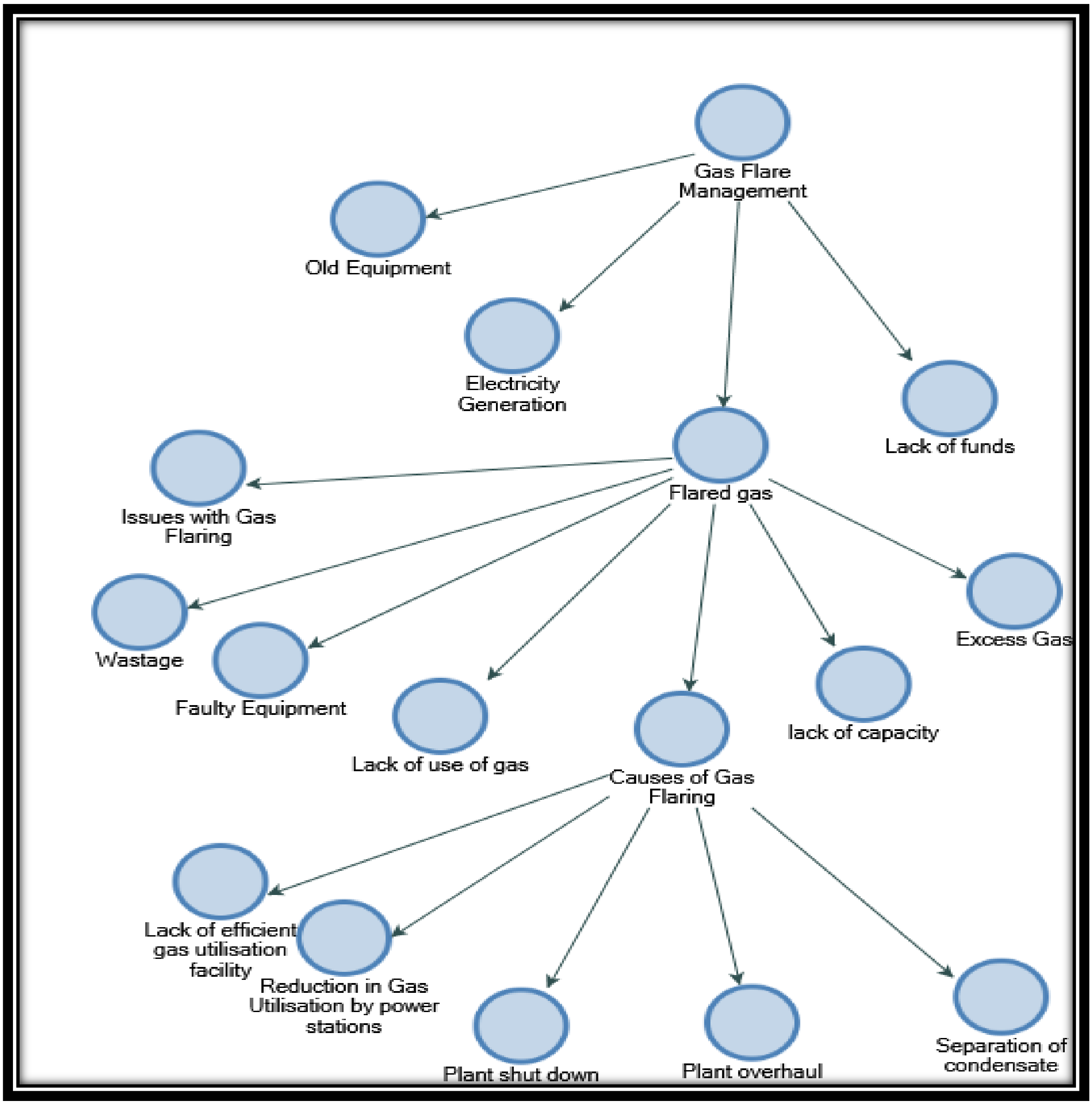

Figure 4. 3: Gas Flare Management Theme

As shown in the Figure 4.3 above, the theme of gas flare management was one of the major themes of this research. This theme was formed from analyzing and finding the relationships between several factors identified through the analysis process. The main categories forming this theme were causes of gas flaring; issues with flared gas; funding issues among many others. All these factors shall be concisely discussed later in this chapter during the presentation of the results of the research.

Another major theme was that of gas production and utilization as highlighted in Figure 4.4 below. This theme was formed from two main sub themes: gas production; and gas utilization, as have been discussed in more details earlier in this Chapter.

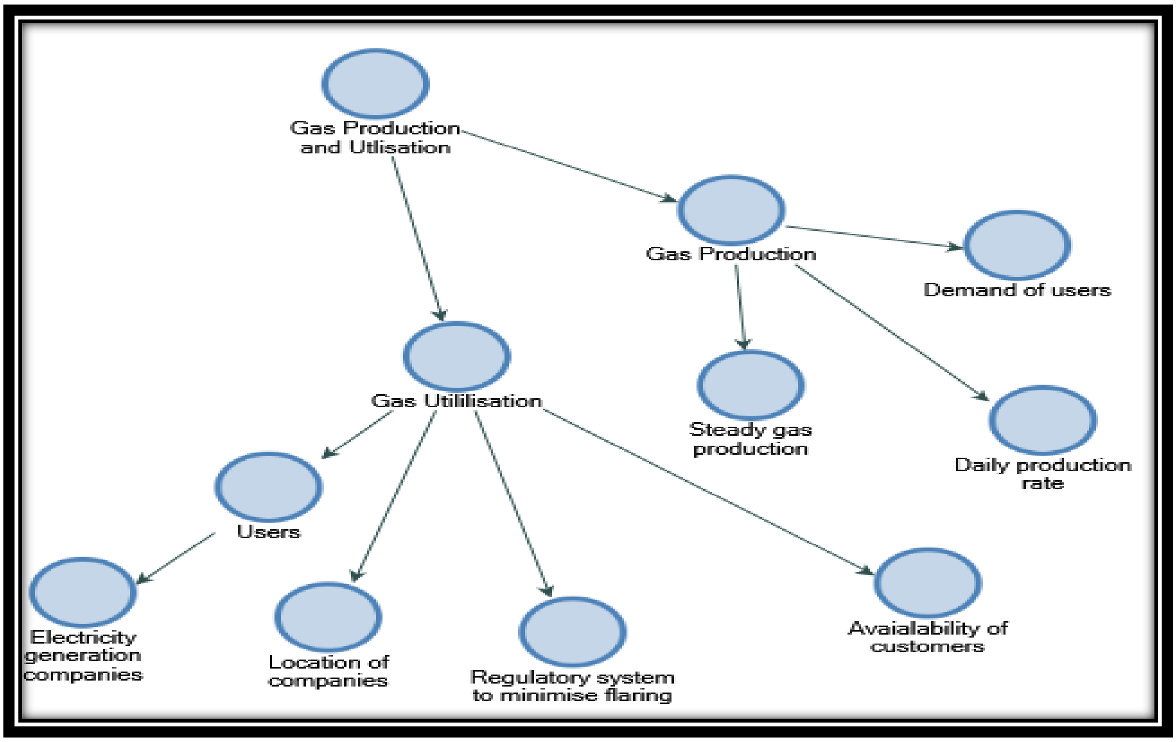

Figure 4. 4: Gas Production and Utilisation Theme

4.3 CASE STUDY COMPANY ONE – OIL AND GAS PRODUCTION COMPANY (CS-1)

4.3.1 Introduction to Case Study Company 1

Case Study Company 1 was conducted using an oil and gas production company herein referred to as CS-1. Data collection from CS-1 was done through in-depth interviews with five key personnel in the company, documentary analysis, and site observation. This introductory section for CS-1 presents the company background, case study description, and the background of the participants in the study.

4.3.1.1 Company Background

The Shell Petroleum Development Company of Nigeria Limited (SPDC) was awarded the contract for construction of the Gas Station in Niger Delta region, Rivers State in 2005. Work on the project began in 2005 and included a gas receiving facility and six new gas wells. The Gas Station bears the responsibility for production and provision of gas for the operation of the nearby power plants. The Gas Station was chosen for this research for the following vital reasons:

i. It is a gas producing and flaring organization.
ii. It supplies gas to nearby power plants.
iii. It is in proximity with oil and gas producing communities.

Therefore, from the above stated reasons, it is obvious that the Gas Station fits into the plan of this research which aims at developing a framework that manages gas flaring in the oil and gas sector, so as to reduce waste and environmental impacts.

A portion of the gas that is produced in CS-1 is transferred to a national organisation known as Nigerian Gas Company (NGC), which in turn passes the gas to the nearby power plants. The NGC was established under the NNPC group to alleviate and regulate the domestic gas market with overflow to neighbouring West African countries like Togo and Benin Republic. The NGC also has the responsibility for establishing sufficient reservoirs, conducive for gas re-injection/storage, processing plants and a network of supply and distribution pipelines across its projected market space with the Nigeria Liquefied Natural Gas Company (NLNG) in Bonny. It has more than 1,000 km of pipeline with gas systems and fourteen compressor stations. About

75% of its sales are to four thermal power stations in Nigeria, which are currently under the control of Power Holding Company of Nigeria (PHCN).

4.3.1.2 Case Company Description

Case Study Company 1 is a gas producing organisation situated in a small Community in the Niger Delta region of Nigeria. It produces 240 million standard cubic feet of gas per day (7.2 million cubic meters). It is a scope of the Afam Integrated Project that was originally initiated to supply the base load gas requirement of the case studies 2 and 3 (190MMscf/d) and about 50MMscf/d swing supply to the Aluminium Smelting Company of Nigeria (ALSCON - through the existing NGC manifold and pipeline). This Gas Plant provides the gas for case studies 2 and 3; and equally support domestic gas supply network around Nigeria. It combines both the conventional and advanced Twister technology, the first of its kind in Africa for gas processing. It can process 240 million cubic feet of gas each day and is being supplied from six gas wells drilled for the project.

The gas plant consists of a 240MMscf/d JT-LTX High Pressure train and a 120MMscf/d Twister-LTX Low Pressure train, condensate stabilization with Flash Gas compression, metering, storage and export facilities. The Gas Station also comprises the Afam Field Manifold with five incoming 8-inch flow lines from the Afam wells and one 12-inch 11 km bulkline from the Afam Field Manifold to the Gas Plant and various other gas and condensate pipelines and flowlines of diameters from 4-inch to 16-inch with lengths from 1.2 up to about 12 km.

The project started in the year 2006 and was completed in the year 2008. It is also worth stating that this project used an investment cost of about $875 million (IMPAC, 2014).

4.3.1.3 Background of Participants

Interviews were carried out on five (5) key personnel within the organisation. Table 4.1 highlights a brief background of the participants interviewed. The choice of these interviewees was based on the fact that the results from the interview would serve as a guide to develop a framework for gas flare management. Therefore the choice of high profile staff was essential and has been stated below.

Production Manager: The production manager in CS-1 plans and organises the production schedules of gas. He is also mandated to regularly assess project and resources requirement in the site. The production manager determines the quality control standard within the organisation and also oversees all production processes.

Health and Safety Manager: The office of the health and safety manager is a vital position due to the hazards associated with gas production and flaring. He ensures that the working environment is healthy and also mandates members of staff to constantly comply with safety protocols like making sure the workers are fully equipped with their personal protective equipment during operations and within the site. It is also the responsibility of the health and safety manager to partner with both employers and employees to accomplish a working condition that is devoid of injuries, accidents, operational losses and occupational health problems.

Operations Supervisor: The operation supervisor is responsible for a lot of responsibilities which include but not limited to oversee of the organisation's financial management, planning and systems control; payroll management; arrangement of fiscal documents and; development of schedules foe regular meetings with Board members of the organisation.

Field Operator: Two field operators were interviewed. The field operators are mostly involved and actively involved in the operations of gas production.

Table 4. 1: Brief Background for CS-1 Interviewees

Position	Gender	Year of Experience
Production Manager	Male	20
Health and Safety Manager	Male	23
Operation Supervisor	Female	15
Field Operator 1	Male	22
Field Operator 2	Male	10

4.3.2 Presentation of Results from Case Study Company 1

Throughout the case study, an effort was made to collect data on the activities of CS-1 to capture the process of oil and gas production as well as the issues leading to gas flaring in the company.

The backgrounds of the participants have been provided in (see Table 5.1). The results from the interviews, documentary analysis, and site observations are presented in three main themes: gas production and utilisation; gas flaring; and gas flare management.

4.3.2.1 Gas Production and Utilization in CS-1

Though the company was involved in both oil and gas production as reported in the survey results, this case study focused on the gas production aspect of the company. In an interview with the production manager, it was confirmed that one of the basic activities that took place in the organization is gas production. Gas production is a steady and daily activity in this company. As gathered from the production manager, '*On a daily basis, the average amount of gas that we produce here is 240 million standard cubic feet (240 mmscfd), but this figure can still vary depending on a vital factor, which is the demand and utilization of gas from the end user of gas'*. Further enquiries showed that in a situation whereby the demand from the customers becomes less (lower than 240 mmscfd), there is a regulatory system which automatically causes reduction in gas production, thereby leading to reduction in gas flaring. The Operations Supervisor shared similar comments to suggest that gas production is not fixed at a particular volume.

A common trend gathered on the production of gas from all interviewees was that, the daily volume of gas production is directly proportional to the demand of the external organizations that utilize the gas being produced. Although there is a provision for the management of gas production in situations whereby the gas utilizing organizations require lesser daily amount, there is no alternative plan to increase the production volume in case of increased demand in gas usage by the external organizations. This was confirmed by the Operations Supervisor when he was questioned on why they don't produce more gas than the current levels. In his own words: *'So far we haven't had any need for increased gas production because our clients who demand the gas have never asked or gone beyond the standard of 240 mmscfd; however, if they should demand for more, we shall find a way to serve them'*. This suggests that, the company has not yet set plans in place for increased production of gas should the need arise.

The amount or level of gas production depends to a large extent on the customers' demand-capacity. The main customers of the company are two electricity power stations, which are located in close proximity to case company. In general, the gas plant in the company produces 240 mmscfd. Of this capacity, CS-2 is indirectly supplied with 50 million standard cubic feet per day (mmscfd) through the Nigeria Gas Company (NGC); while CS-3 is directly supplied with and utilizes 120 mmscfd. Also 50 mmscfd is supplied to the Aluminum Smelting Company of Nigeria (ALSCON) through the existing NGC manifold and pipeline. When questioned about what happens to the remaining 20 mmscfd of gas produced, the response was that it was subjected to constant flaring. A mechanism was however in place to ensure the company does not flare beyond this quantity. In a situation whereby the demand from the customers becomes less, the company has a regulatory system which sends a signal to the gas production plant to ensure the production is minimized to reduce waste (flaring).

4.3.2.2 Gas Flaring in CS-1

There is constant gas flaring of 20 mmscfd in this company. During data collection and precisely during site observation, gas flaring was witnessed taking place from the flare stack in the company. A visit to the production plant showed some level of gas flaring as identified primarily during the observations that were carried out in the site and shown in Figure 4.5. Also witnessed is the heavy dark smoke that goes along with gas flaring from the site. The study enquired to identify the major cause(s) of the gas flaring in the organisation. The responses to the interviews carried out on top ranking personnel of the company established six (6) major causes for gas flaring as discussed below.

Figure 4. 5: A typical Gas Flaring Scene in CS-1

The flaring process in this gas station is as a result of several reasons which have been specified in the corresponding sub sections:

4.3.2.2.1 Lack of efficient gas utilization facility

It was identified through the interviews that beyond the 20 mmscfd flared on daily basis, there were many instances where the customers failed to utilize the quantities set for them and this led to gas flaring. As explained by the field operator 1, *'we mainly supply to two companies a particular quantity of gas on daily basis, sometimes they demand less than that as they may not be able to utilize up to the agreed quantity and in such cases, we tend to flare more gas'* This was confirmed by the operations supervisor who made the following statement: ' *the Gas Station was designed to supply gas to two power stations, but unfortunately, these clients have consistently failed to live up to expectation in terms of gas utilization. In fact, one of them particularly has insufficient and dilapidated gas turbines in the power plant*.' According to the Operations Supervisor, lack of efficient gas utilisation facility is a major challenge on gas flaring on the site. In an interview with the health and safety manager of the company, he also confirmed that the case company was one of the main reasons why they flared gas. He suggested that though they have a system in place to ensure they reduce flaring by reduction in gas production if demand by clients reduces, they still flare gas regardless of this mitigation plan. The production manager also had this to say concerning the mechanism in place for regulating production in case the customers cannot utilize all the gas produced: '*You see, even though we have a system in place where we can send signals to reduce production when a client cannot utilize all the gas we are producing for them, there is still a high volume of gas flared between the change in production levels and the time we receive the information'.*

All interviewees pointed to the fact that lack of gas utilization on the part of the company's clients is one main reason for which gas is flared and this occurs when there is a reduction in demand by customers: Whenever there is a sudden trip (reduction in consumption) from customers, namely the Afam Power Station and Nigerian Gas Company, it brings about excessive pressure to the inlet valve. To avoid disaster, and also for safety reasons, the excess gas is channeled to the flare stack.

4.3.2.2.2 *Reduction in gas utilization by power stations*

This is another reason for gas flaring in the Gas Station. This is as a result of power failure or lack of use of gas to generate electricity by the Afam Power Station. During routine maintenance or unplanned maintenance in the power station, there could be lack or less generation of electricity, and this signifies that all or some of the turbines might not be operational. Therefore, lesser gas will be utilized. This causes the Gas Station to have more gas than it can store. In this situation, the excessive gas in the plant is channeled to the gas stack for flaring. This is mostly for precautionary reason.

4.3.2.2.3 Plant shut-down

Production shut down was identified from the interviews as one of the key reasons by which gas is flared in this company. There are two types of plant shut-down in the company, which led to gas flaring: the Planned shut-down; and the Un-planned shut-down.

Unplanned shut-down, also known as emergency shutdown was identified to happen due to loss of control or emergency situations like fire outbreak in the facility. In such a situation, there are measures to keep the gas plant safe, which involve instant shutting down of the plant resulting in subsequent gas flaring in the Gas Station. In such a situation, all the gas in the plant has to be flared for health and safety reasons. There could also be a case of process upset – large number of vessels shut down, thereby causing chain shut down. From the interview with the Production Manager, it was identified that although this was a rare occurrence, whenever there were any such signs of a fire outbreak; the company does not take chances and immediately proceed to shut down in emergency situations leading to gas flaring. The Health and Safety manager made the following comment: '*The risks in this business are high and you do not want to take a chance with the slightest fire. We however have systems in place to quickly confirm if it is a real fire or a false alarm. Once we confirm it is a real fire outbreak, we have very little time and as such we proceed with the safest option which is emergency shut down of the plant and once we do this, gas definitely has to be flared'.*

Planned shut-down is a type of shut-down that is pre-planned and arranged. It could last for about 1 – 2 weeks based on the reason for the shut down and in such situations; the gas is channeled to the stack and lost through flaring. This was identified through the interviews to be more of a maintenance process and does not bring about large volume of flared gas because before it proceeds, some control measures are put in place to reduce volume of gas production.

4.3.2.2.4 Separation of condensate

Another cause of gas flaring as part of the company's processes is the separation of condensate from gas. As informed by the operations supervisor, '*During separation of condensate from gas, there is need to stabilize the liquid and this leads to the gas being flashed off.*' The field operator suggested that separation of condensate leads to flared gas when there is no flash-gas compressor. According to Production Manager, '*though in the absence of a flash-gas compressor more gas is flared, it is worthy to mention that this happens in rare cases – only when the flash-gas compressor becomes faulty*.' According to the Operations Supervisor, this has happened just once since the inception of Gas Station. He however iterated that though this was a rare occurrence, anytime it happened, it led to large volumes of gas flaring by the company.

4.3.2.2.5 Plant overhaul

Another source of gas flaring as identified from the case study company is the flaring of gas during maintenance operations due to plant overhaul. The respondents suggested that, there were periodic maintenance operations as well as unplanned maintenance operations where the plants have to be shut down to ensure maintenance is carried out. During these two scenarios, there is some amount of gas that gets flared. The Operations Supervisor differentiated this from the plant shut down discussed above. In his words: '*Plant overhaul as a source of gas flaring is different from plant shut down. With plant overhaul, we have to perform maintenance operations and this can be a monthly maintenance as we have plans for, or a development of fault in the plant where we have to quickly repair. Shut down can be as a result of any other reason, but here I am talking about repair works.'*

All the other respondents confirmed that plant overhaul is a source of gas flaring although plans are always in place to ensure the amount of gas flared during such a process is minimized, especially for planned maintenance. As a general rule within the organisation, majority of the gas flared within the company is from lack of efficient gas utilization. According to the Production Manager and Operations Supervisor, about 90% of the daily routine gas flaring of 20 million mmscfd is largely due to lack of efficient gas utilization facility, while the remaining 10% is distributed among the other five causes as seen in Figure 4.6, as follows: Reduction in demand by customers (3%); Plant shut-down (2%); Separation of condensate (1%); Reduction in gas utilization by power stations (2%); Plant overhaul (2%).

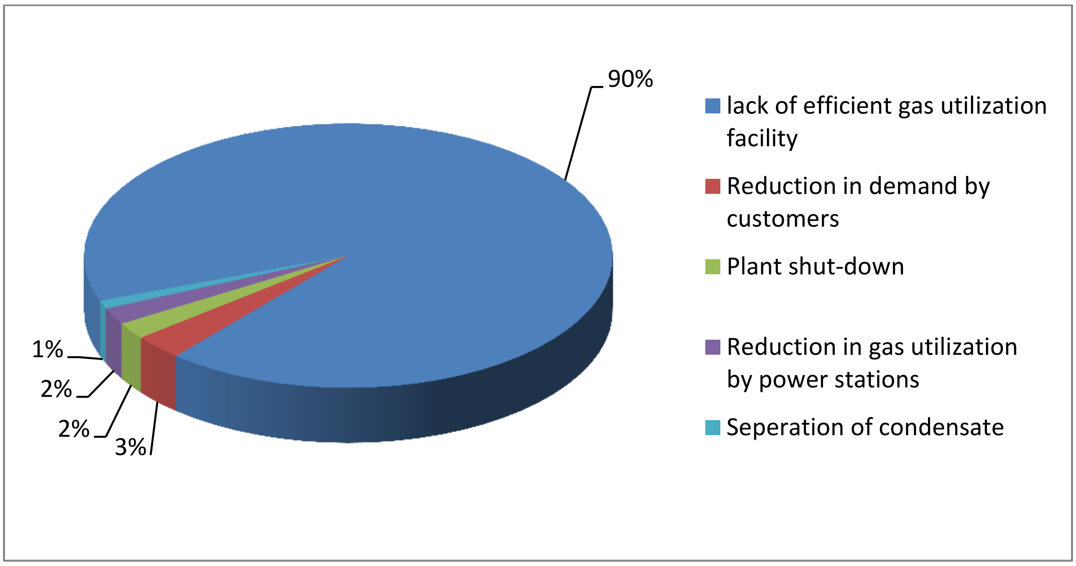

Figure 4. 6: Leading causes of gas flaring in gas station

4.3.2.3 Gas Flare Management in CS-1

Due to the high levels of gas flared by the company, there was the need to investigate the systems in place for them to manage the gas flared or to mitigate the chances of gas flaring. The interviewees were first asked whether gas flaring in the company was avoidable. The general position of all interviewees was that gas flaring was to some extent avoidable. According to the Production Manager, gas flaring was only available if: '*If our clients, particularly the power stations improve the working conditions of their gas turbines, this will automatically increase gas consumption, and reduce the volume of gas flaring in our site. On another note, the gas flared in our site is a safety precaution. We flare to reduce pressure on the equipment. At times, the gas flaring within our site is due to the maintenance of the gas plant: during this period, any remaining gas in the process plant is systematically flared to avoid any form of hazard like fire disaster'.* All other interviewees confirmed that gas flaring to a large extent was unavoidable but could be managed or reduced very considerably. Due to this, the company had in place different means to mitigate the extent of gas flaring occurring and to reducing the amount of gas flared.

Field Operator 2 was of the view that, though they wish to stop gas flaring, it was not entirely up to them. In his word: '*Yes, we hope to prevent gas flaring in the site. However, I cannot state when this will take place, because it has to be a decision of the management of the organisation. This will also involve the parent company of this organisation.*'

Of all these, production of electricity was identified as the most recognised way to manage or reduce the amount of gas flared. The Operations Supervisor puts it this way: '*Having worked in this organisation and being in this site since the inception, I will suggest that the gas be utilised for the production of electricity. My opinion is based on the fact that electricity is constantly a need in Nigeria, and with the abundant natural gas in Nigeria, it can be viable and sustainably serve the purpose.'* Other interviewees suggested gas to wire (GTW) will be a very good means to manage gas flaring as the gas could be converted to a better use. Other technologies were suggested as a means to reduce or manage gas flaring. The one of the field operators during the interview gave this response: '*From my personal point of view as someone who has been in this industry for over 20 years of service, I advise that it is important for other technological management tools to be put in practice too, like liquefied natural gas (LNG) and gas to liquid (GTL). It is necessary for an understanding of agreement among the gas producing/flaring organisation, the electricity producing organisation and the government*'. Three of the other interviewees also suggest that LNG and GTL would be very good means of reducing gas flaring too, aside GTW.

The interviewees were asked to indicate which of the technologies or methods for gas flaring reduction would have the most impact. The interviewees suggested that GTW will be the most effective means of reducing gas flaring and will work effectively in the Nigerian context. The Operations Supervisor had this to say: '*I am of the opinion that it can work effectively. This is because, first and foremost, electricity is one important area in Nigeria that needs to be put in good order. With electricity comes improved infrastructural development, which improves the entire national economy. With available gas turbines for the gas, there will be steady utilisation of gas which leads to minimal available gas for flaring (if any).*'

Though the company is very keen on mitigating or reducing the amount of gas flared, it faces a number of challenges such as lack of cash flow; disruption of pipelines by the people within the local communities; and lack of government support. The Production Manager answered the question on challenges this way: '*In our organisation, we are faced with some fundamental supports from the government. As an organisation, we also lack the financial capability to solely curb away this problem of gas flaring in Nigeria. We also experience a situation whereby the local communities sabotage our equipment and this sort of scenario adversely affects the organisation's plans to minimise gas flaring. For example, we have experienced where some* *local youths damaged our gas pipelines and this situation caused a huge volume of gas being wasted. This caused a huge financial loss to the organisation'*

Other interviewees recounted series of serious issues affecting their company's attempt to reduce gas flaring and as such suggested government support as one key means to reduce gas flaring and all respondents agreed that it will be very welcoming to have some interventions from government. The production manager had this to say: *'Yes, various forms of support are required from the government.' He continued: 'we need some incentives from the government like tax reduction and tax holidays. We also need some enabling policies to be implanted by the government.'*

Financial issues were identified to be some of the most pressing challenges faced by the company. For this reason, interviewees suggested that any intervention in that regard will positively influence their activities. Interventions such as policies that encourage and benefit them like lower bank interest rates which will encourage them to borrow from the banks and execute towards gas flare management technologies. The production manager had this to say: '*If you look around in Nigeria now, you will find out that the bank interest rates are very high; moreover, when banks realise you are from a multi-national oil and gas company, they even tend to give you loans on a higher interest rate.'* Government intervention is therefore needed to ensure gas production companies put in efforts to reduce or manage gas flaring.

4.3.3 Conclusions from Case Company 1

As a gas producing company, the case company directly or indirectly supplies gas to three organisations, which utilises gas for both electricity generation and aluminium production. This study identified that average of 20 mmscf of gas is flared daily from the site, but could be higher depending of usability of various clients. The study also identified the major sources of gas flaring, which included lack of efficient gas utilization facility, plant shut-down and plant overhaul. Although there is some level of gas flare reduction processes going on in the company, the results suggested that more efforts are needed to achieve a substantial result towards gas flare reduction. This is because the interviewees stated that the technologies used in gas flare reduction are either not effective or partially effective. It is very necessary therefore to improve gas utilisation aimed at reducing gas flaring; and this will obviously contribute to greener environment, improved health and safety as well as improved economy.

4.4 CASE STUDY COMPANY TWO – ELECTRICITY GENERATION COMPANY (CS-2)

4.4.1 Introduction to Case Company

Case Study Company 2 is one of two electricity generation companies used as basis for collecting data, herein referred to as CS-2. This section discusses the background to the case study under three main themes: company background, which also encompasses case description and the backgrounds of case study participants and; the presentation of results.

4.4.1.1 Company Background

CS-2 is an electricity generation organization, and it is the first major gas-turbine station that was built in Nigeria (Eti *et al.*, 2004). It is located in one of the communities that make up the Niger Delta region, which is the oil and gas resource depot of Nigeria. This power station is one of the generating stations, as well as one of the oldest power stations in Nigeria. It was established in 1962 and currently comprises five (5) groups of plants. For the sake of this research, we shall know them as PS-I, PS-II, PS-III, PS-IV and PS-V, with a total of 20 units of gas turbine. The first phase, PS-1 was constructed and commissioned in 1963. It consisted of four- generating units (GT1 – GT4). GT1 and GT2 have an installed capacity of 10.3MW each, while the GT3 and GT4 have installed capacity of 17.5MW each. It is worth mentioning that due to local economic growth that was experienced in the seventies, there was need for construction/installation of PS-II, which accommodates four additional power generating units (GT5 – GT8), each with an installed capacity of 23.9MW, which was officially commissioned in 1976. This was followed by four gas turbines of 27.5 MW each, commissioned in 1978 and known as PS-III. In 1982, six generating units, with installed capacity of 75 MW each were added to the power station, and this is the PS-IV. There was further commissioning of the latest generating units, which incorporated two generating units of 138MW each, which is known as PS-V. This rapid growth ensued despite enormous technical problems with the individual generating units and the auxiliaries. These have caused forced or emergency outages, long or delayed downtime, high cost of power generation and erratic power supplies from the station.

4.4.1.2 Case Company Description

The primary operation of the organisation is electricity production. In entirety, there are 20 units of gas turbine of different capacities in this power station, but currently there is just one effective gas turbine, and it generates a daily electricity of 65 MW. Unfortunately, the rest are either faulty or decommissioned due to wear and tear, or as a result of extreme high temperature conditions the gas turbines endure during their active life time. Due to the fact that this power station is owned by the federal government, its product is automatically transferred to the national grid to improve the national electricity generation capacity. Although the power plant has just a gas turbine for its operation, it has enough land mass to accommodate up to 5 more extra turbines, if they are available. As a thermal power station that operates with gas turbines, it receives its gas supplies directly from the nearby gas plant.

Therefore, from this case study company, we are interested in finding out the link between the gas station and the power station with regards to gas supply from the gas station and gas utilisation and electricity generation from the power station. It was also necessary to look at the challenges that this power station faced and how to improve gas utilisation; thereby reducing the volume of gas flared due to lack of utilisation.

4.4.1.3 Background of Participants

Interviews were carried out on five (5) key personnel within the organisation. Table 4.2 highlights an overview of the participants in the interview. The choice of these interviewees was based on the fact that the study intends to use the results from the interview as a guide to develop a framework for gas flare management, therefore the following key position with responsibilities were chosen and interviewed:

Power Plant Operator: The major responsibilities for this position include control of generator output to match the phase, frequency, and voltage of electricity supplied to panels; monitor and inspect power plant equipment and indicators against operational problems; regulation of the flow of power between generating stations and substations.

Operations and Maintenance Manager: Responsibilities include implementation of preventative maintenance programs; design of maintenance programs; enforcement of industry requirements; assessment of risks.

Electrical Maintenance Repairer: Installs and repairs any electrical equipment that develops faults in the site.

Technical Manager: Technical manager provides enabling working atmosphere to project teams and ensure objectives are met within stipulated time; provide direction and technical expertise in design, development and systems integration among other responsibilities.

Shift Supervisor: Responsibilities for this position include conducting employee performance reviews; supervision of production line operations in accordance with the electricity generation policies; mutual communication with the plant manager and train production line employees when necessary.

Table 4. 2: Brief Background for CS-2 Interviewees

Position	Gender	Year of Experience
Power Plant Operator	Male	11
Operations and Maintenance Manager	Male	18
Electrical Maintenance Repairer	Male	12
Technical Manager	Male	6
Shift Supervisor	Male	22

4.4.2 Presentation of Results from Case Study CS-2

Throughout the case studies, efforts were made to collect data on activities of the company with major emphasis on electricity generation and the problems faced by the company. The results from case study 2 are discussed in this section based on 9 (nine) main themes: electricity production; sources of gas for gas turbines; typical problems in the power station; general plant condition and maintenance; quality of electricity generation; volume of gas utilization in power station; electricity tariffs; strategy to improve electricity generation; and strategies to improve site operations. These themes are discussed below.

4.4.2.1 Electricity production

The case company produces far less than its electricity generation potentials. According to the Power Plant Operator in the interview, he said *'This power station is unfortunately not where it's supposed to be in this country. This is because it is one of the pioneer power stations in this country and also has high number of employees, and even has an active gas station by the corner. In fact, sometimes, we are surprised that we have such a big power station like this, yet in reality Nigeria still encounters severe electricity problem. Currently we produce just 65 MW capacity of electricity, while this station has an original capacity of over 900 MW of electricity. So my brother you can understand what I'm talking about'.*

4.4.2.2 Sources of gas for gas turbines

This research enquired on the steady availability of gas from the gas plant to the power station. This is because it is essential to know if the gas produced and supplied is capable of sustaining the gas need of the available turbines. From the findings, there is regular supply of gas, however, on occasional situations, there could be a problem with the trunk line, and this inhibits the availability and supply of gas. The Operations and Maintenance Manager of the gas plant states that *'in such a situation whereby the trunk line encounters a problem, it is his responsibility to alert the power plant operators as quickly as possible and create the awareness for expected gas shortage. However, he further stated that the gas plant is also equipped with a gas reservoir tank which is capable of storing gas that could serve their clients for about three hours, pending rectifying the cause of problem. However,* in a situation that the trunk line encounters a problem that lasts for more than three hours, there would be lack of gas production and supply to the power station, which will lead to lack of electricity production. It was identified that having another source of supply of gas will further guarantee electricity production.

CS-1 (Gas Station) primarily supplies gas to the CS-2 for the operation of the gas turbines in the Power Station – CS-2. However, the Gas Station does not directly supply to CS-2, rather it supplies to the Nigerian Gas Company (NGC), which directly supplies to this Power Station. It is worth mentioning that the distance between this Power Station and the NGC is about two kilometers; while the distance between this Power Station and the Gas Station (CS-1) is about four kilometers. However, distance is not the motive for the indirect supply of gas to this Power Station; rather this is because the NGC has long been responsible for such duty since the inception of this Power Station. It has a pipeline channel through which gas is supplied to this

Power Station. In addition, it is just about two kilometers away from the Gas Station. Secondly, there is an economic factor. Supplying directly from the Gas Station to this Power Station will require new pipelines to be laid, as well as other infrastructures needed for smooth operations.

Records from this power station as at August in 2013 showed that it received and utilized 60 million cubic meters of gas per day (mmcmd). However, Table 4.3 shows the cost and volume of gas utilised from January to December in 2011. The Electric Company utilised about 300million to 600 million standard cubic feet (SCF) monthly, depending on availability of turbines. This process generated about £1.1 million to the Gas Company at 1000 SCF, costing £0.16. The gas consumption as specified in the table is unstable and varies monthly. This variation is obviously due to the number of active gas turbine(s) during each month. In November, December and August, the Electric Company experienced the highest volume of gas consumption and that is connected to the availability of about 5 to 3 active gas turbines, as compared to September, June and January, which had varying number of active gas turbines from 3 to 1. So there is turbine reliability and their maintenance issues.

Table 4. 3: Monthly Gas Consumption and Cost Report in CS-2

MONTH/YEAR (2011)	QTY. OF GAS CONSUMED (SCF)	COST (£) @ 0.16 PER 1000 SCF	VAT 5% (£)	TOTAL (£)
JANUARY	263,977,909	29,885.00	1,494.25	31,379.25
FEBRUARY	331,047,600	37,478.00	1,873.90	39,351.90
MARCH	325,646,105	36,866.50	1,843.32	38,709.70
APRIL	373,903,442	42,329.7	2,116.49	44,446.20
MAY	303,831,081	34,396.80	1,719.84	36,116.60
JUNE	237,094,291	26,841.50	1,342.08	28,183.60
JULY	403,409,273	45,670.10	2,283.50	47,953.60
AUGUST	531,371,512	59,402.00	3,007.84	63,164.60
SEPTEMBER	232,252,347	26,293.40	1,314.67	27,608.00
OCTOBER	408,281,458	46,221.70	2,311.08	48,532.70
NOVEMBER	617,699,973	69,930.00	3,496.50	73,426.50
DECEMBER	536,807,964	60,772.20	805,211.95	63,810.80
TOTAL	**4,565,322,935**	**516,841.00**	**25,612.40**	**1,108,730.00**

4.4.2.3 Typical Problems in the Power Station and Reasons for Poor Electricity Generation

There is a huge concern about the operations in this power station particularly on issues relating to poor state of turbines in site and constant reduction in electricity produced. In a one-on-one interview with the operations and maintenance manager of the organisation, the the reason(s) responsible for such were asked, and his answer was:

'I have been with this organisation for over 27 years. It is not a good thing to say that for the past 17 years, we have continually experienced deplorable state of our equipment and plants. The reasons for reduced electricity output in this organisation are not far-fetched. I will start with the most obvious, which is lack of effective and viable gas turbines. Also I must state here that these gas turbines got this bad condition mostly because we do not have an effective maintenance that is routinely carried out as at when it is due. We also lack a quality maintenance team that is easily assessable to the power station. In this organisation, there are times when we do not also have gas fuel to even operate the gas turbines. And sad to say, you know this is an organisation that is fully controlled by the government, so most of the times we are at the mercy of the government for funding. Sometimes, the funds come very late and at some other times, we do not even get any funding to carry out necessary projects. So when you carefully look at the reasons I have stated, you will understand why we produce far below our expectations in this power station'

Based on the response from the operation and maintenance manager of the power station, the problems faced by the power station are discussed below:

4.4.2.3.1 Lack of Funds

To successfully run a power plant requires the availability of money. This is needed for routine maintenance of the power plant (planned and unplanned), payment of staff salary and other logistics. The shortage of funds facing the power station may be linked with the fact that it is a federal government parastatal and not funded sufficiently; and the issue of fund mismanagement within the corporation may not be ruled out. However, the PHCN has been privatized since October 2013, hopefully, this could bring improved funding into the power station.

4.4.2.3.2 Lack of Spare Parts

Spare parts are vital for the maintenance of the equipment used in the power station. Unfortunately, most of the turbines in this power station are outdated; therefore their spare parts are not readily available, and sometimes are unavailable. This leads to scarcity of spare parts when they are needed and, this eventually led more than 50% of the units been rendered obsolete.

4.4.2.3.3 Lack of Trained Local Maintenance Team

Another problem that affects this power station is lack of trained and capable maintenance experts that could carry out adequate maintenance on the station when necessary. This has led to regular invitation of foreign experts from Sweden for all the planned maintenance operations in the station whereas with available local experts, this could be less expensive.

4.4.2.3.4 Irregular Gas Supply:

This problem arises due to sabotage on the gas line. If there is damage or a threat on the pipeline that connects gas to this power station, or a threat or damage to any of the pipelines associated with the NGC or the gas station, gas supply is automatically cut off to avoid hazard. A typical example of occurrence is when the pipeline that accommodates condensate is vandalized, the gas station is faced with the problem of condensate storage: and the immediate means of solving the problem is to stop gas production, and inevitably this leads to shortage or lack of gas supply to this power station. This process affects the electricity production.

4.4.2.3.5 Lack of Gas Sufficient Turbines and the Presence of Faulty Turbines:

This power station currently has 20 gas turbines, but only one turbine is functional as at time of study; while the rest are either decommissioned or faulty. The shift manager during an interview section (when asked about the average number of people who work in the site daily) said *'I cannot say exactly because the number is totally dependent on the number of effective and active turbines at each specific day. For example we have just one active turbine today, so the number of people to be on duty in the turbine operations department will be low because there is no demand for staff. But if all the turbines are working, then the expected number of workers will increase. But unfortunately I just cannot give you any figure now please'.*

4.4.2.4 General plant condition and maintenance

To help identify the issues in CS-2, the research investigated the conditions of the plants in the company. From the observation carried out during site visits, an insight into the true condition of infrastructure, or most particularly the nature of the equipment in the power station was ascertained. During the time of visits to Power Station (CS-2), the PS-I, PS-II, and PS-III had become obsolete and decommissioned. The operations and maintenance manager stated that decommissioning of the plants was due to a combination of reasons - *unavailability of spare parts, lack of maintenance, lack of funds, or general wear and tear due to usage'.* Out of six units of gas turbines installed in PP-IV, five units of gas turbines were reported non-functional and awaiting rehabilitation; while one unit of gas turbine is functional, yet it produces 65MW of electricity instead of the installed capacity of 75MW. Figures 4.7 and 4.8 show the front and side views of obsolete gas turbines as seen in the Power Station.

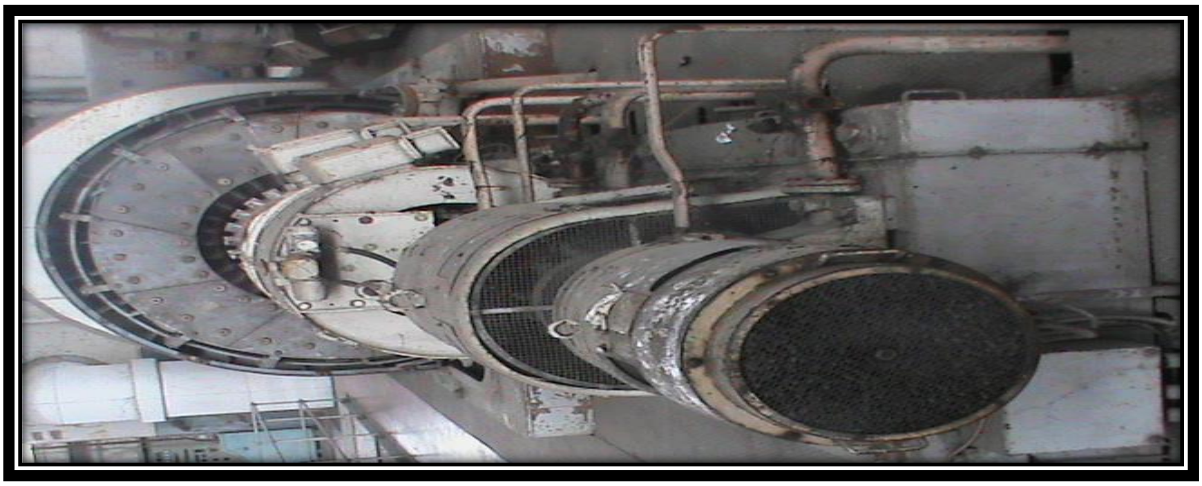

Figure 4. 7: Front View of Gas Turbine in CS-2

The company was struggling with keeping their turbines in good shape and it was reported that lack of funds was one of the main reasons for such condition.

Figure 4. 8: Side View of Gas Turbine in CS-2

Subsequently, as seen in Table 4.4, the gas turbine is in very poor condition and this contributes to the low productivity occurring at the plant. The gas turbines in the case company (CS-2) are in a poor state of maintenance, with only 5% of the total plants in good working condition, thus affecting performance of the station. Out of 20 units of turbine in CS-2, 13 units are completely written off, 6 are temporarily out of service due to one fault or another, and just 1 turbine is currently generating electricity.

Table 4. 4: Current Plant status in CS-2 as at 2013

S/NO	UNIT	MANUFACTURER AND TYPE	YEAR OF COMMISSIONING	NAME PLATE RATING (MW)	PRESENT CAPACITY (MW)	UNIT CONSTRAINT	DATE OF LAST MAJOR OVERHAUL	REMARK
1	GT 1	ABB/12	1963	10.3	0	Unit Obsolete	21/06/1978	Decommissioned
2	GT 2	ABB/12	1963	10.3	0	Unit Obsolete	08/10/1979	Decommissioned
3	GT 3	ABB/12	1963	17.5	0	Unit Obsolete	13/03/1982	Decommissioned
4	GT 4	ABB/12	1963	17.5	0	Unit Obsolete	21/11/1979	Unit Obsolete
5	GT 5	ABB/9C	1976	23.9	0	Unit Obsolete	15/09/1983	Decommissioned
6	GT 6	ABB/9C	1976	23.9	0	Unit Obsolete	08/06/1979	Decommissioned
7	GT 7	ABB/9C	1976	23.9	0	Unit Obsolete	30/07/1979	Decommissioned
8	GT 8	ABB/9C	1976	23.9	0	Unit Obsolete	08/06/1985	Decommissioned
9	GT 9	ABB/9C	1978	27.5	0	Unit Obsolete	09/09/1985	Decommissioned
10	GT 10	ABB/9C	1978	27.5	0	Unit Obsolete	1983	Decommissioned
11	GT 11	ABB/9C	1978	27.5	0	Unit Obsolete	01/05/1981	Decommissioned
12	GT 12	ABB/9C	1978	27.5	0	Unit Obsolete	1993	Decommissioned
13	GT 13	ABB/13D	1982	75.0	0	Awaiting Rehabilitation	21/10/1988	Decommissioned
14	GT 14	ABB/13D	1982	75.0	0	Awaiting Rehabilitation	11/03/1985	Compression Blade Failure
15	GT 15	ABB/13D	1982	75.0	0	Awaiting Rehabilitation	1983	Compression Blade Failure
16	GT 16	ABB/13D	1982	75.0	0	Awaiting Rehabilitation	1983	Compression Blade Failure
17	GT 17	ABB/13D	1982	75.0	0	Awaiting Rehabilitation	06/05/2001	Turbine Blade Failure
18	GT 18	ABB/13D	1982	75.0	65	Available	07/01/2002	Unit on Load
19	GT 19	SIEMENS	2001	138.0	0	Awaiting Major Overhaul	Overhaul yet to be carried out	Unavailable due to bearing failure
20	GT 20	SIEMENS	2002	138.0	0	Awaiting Major Overhaul	Overhaul yet to be carried out	Unavailable due to generator stator insulation breakdown

Maintenance in the power station is categorized into two: the planned maintenance and the unplanned maintenance. This research focused more on the planned maintenance at the power station. Data provided by the technical manager suggest that in the Power Station, three variants for maintenance (A, B, C) are required with time-intervals of 4000, 8000 and 16000 evaluated operating hours (EOH) respectively. Table 4.5 gives a clearer scenario of what happens during these various schedules in the power station:

Table 4. 5: Table of Checks and Maintenance Works at CS-2

	A	B	C
Time required to complete job	48 hours	96 hours	6 days – 3 weeks
Mean Time Between Maintenance (MTBM)	4000 hours	8000 hours	16000 hours or 2 years
OPERATIONS			
1. Checks at standstill	- Combustion chamber - Burner - Swirl-body - Fuel nozzle - Turbine blading - Inlet and outlet	- Combustion chamber - Burner - Swirl-body - Fuel nozzle - Turbine blading - Inlet and outlet - Safety equipment - Transformers - Field resistance - Inlet duct - Compressor blading inlet - Lube oil	- Combustion chamber - Burner - Swirl-body - Fuel nozzle - Turbine blading - Inlet and outlet - Safety equipment - Temperature at compressor inlet - General temperature check - All motors - All control equipment
2. Overhaul	- Batteries - Coolers outside	- Batteries - Coolers outside - Recording apparatus - Fans - Brushes and sliprings - Flame detectors	- Batteries - Coolers outside - All bearings - Auxiliary gears - High pressure pump - Turbine and compressor blading
3. Replacement			- Electronic tubes
4. Measurement			- Insulation resistance
5. Cleaning		- All control panels - All insulators	- Generator stator winding
6. Checks at recommissioning	- Acceleration characteristic - Overspeed protection - Temperature	- Acceleration characteristics - Overspeed protection - Temperature	- Acceleration characteristic - Overspeed protection - Generator

	control - Excessive temperature protection	control - Excessive temperature protection	protection - Temperature control - Excessive temperature protection - Blow-off valves

Table 4.5 also shows planned schedule for all the activities to be carried out during maintenance of the station. As gathered from the Electrical Maintenance Repairer however, the schedule is not always adhered to at the plant. The Shift Supervisor also said this concerning planned maintenance: '*Well, we have all the plans in place and we have scheduled times to do all the maintenance works, but to be honest sometimes other things get in the way and we do not do the maintenance as required*.'

4.4.2.5 Volume of gas utilization in power station

As part of the documentary analysis and interviews, it was identified that the energy generated by this power station over 12 years varied greatly. This variation was to a large extent dependent on the availability and working conditions of the gas turbines than on the availability of gas. It was identified that the gas supplier for the station always had enough supply but the station did not always have the capacity to utilize the supplied gas. Table 4.6 demonstrates the yearly consumption of gas from 2007 to 2012, as well as the capacity of energy generated within the same period. 2003 to 2007 witnessed greatest period of generation in the site because during those periods, 4 gas turbines with an average capacity rating of 105 MW were in good working condition. 2010 witnessed the least energy generation because the station was plagued with a number of decommissioned and defective turbines.

Table 4. 6: Energy Generation and Gas Consumption in CS-2 from 2001 - 2012

YEAR	ENERGY GENERATED (MWH)	QUANTITY OF GAS CONSUMED (SCF)
2001	340,194.90	5,610,345,320.00
2002	184,672.10	36,033,153.45
2003	2,090,548.30	26,580,679,429.00
2004	1, 247,813.10	16, 751,698,916.40
2005	1, 838,866.90	23,671,967,482.60
2006	1,864,110.30	24,732,387,663.10
2007	1,393,932.40	17,734,557,698.30
2008	305,340.00	4,749,062,535.00
2009	151,859.00	2,275,220,650.00
2010	95,947.40	966,638,449.00
2011	391,577.00	4,565,322,935.00
2012	497,885.20	7,611,025,455.00
Feb – Sept 2013	600,000 – 650,000	Not Available

However, between February and September 2013, this power station generated between 600,000 – 650,000MWh, depending on the production capacity of the turbines. According to the shift supervisor, the increase *'is basically because of the introduction of three new turbines into the system.'* It was further identified that this has created massive improvement to the national grid and has also improved gas use and financial economy of the country.

4.4.2.6 Suggested strategy to improve electricity generation

All interviewees on case study were asked to suggest, based on their experience, the means to improve electricity generation in Nigeria. Analysis of the suggestions gave about 8 different means by which electricity generation in the country could be improved. A quick overview of the 8 suggested means of improving electricity generation is presented below:

i. Provision of more power stations and gas turbine units, in various locations of Nigeria. According to the technical manager, there is the need to have these power stations in many different places in Nigeria considering the high levels of power outages in the country.

ii. Improving gas supply will make a meaningful contribution to electricity generation in Nigeria.
iii. Power lines should be updated and high voltage overhead lines changed to underground lines if possible.
iv. Surveillance team should be put in place along pipelines routes to managing vandalism and bush burning.
v. Transformers should be regularly updated to replace old/weak transformers.
vi. Encouraging regular line patrol.
vii. Checking and discouraging illegal electricity wire connections.
viii. Stocking of spare parts to ensure turbines and plants can easily be replaced as at when due

4.4.2.7 Summary for Case Study Company 2

In summary for this case company, this study came up with improvement that will benefit the power station. They will potentially improve the management of the power station, support and establish a better working environment and improve electricity production.

i. A written maintenance policy and strategy needs to be published.
ii. A coordinator for planning the work orders, to decide the resources allocations, training, and maintenance executions needs to be appointed.
iii. The planned maintenance procedures and intervals between maintenance should be well defined. This is because poor plant history records make it difficult to retrieve the planned maintenance history especially for the older plants.
iv. A maintenance-culture/commitment through team-based rewards and recognition should be introduced together with employee empowerment.

4.5 CASE STUDY COMPANY THREE – ELECTRICITY GENERATION COMPANY (CS-3)

4.5.1 Introduction to Case Company

Case Study Company 3 is an electricity generation company, herein referred to as CS-3. This section discusses the background to the case study under three main themes: company background, which also encompasses case description and the backgrounds of case study participants and; the presentation of results.

4.5.1.1 Company Background

This is one of the few Independent Power Producers (IPPs) in Nigeria. Technically, this power station produces electricity and transfers to the national grid, as this is the process in Nigeria. However, the financial proceeds from the sales of electricity are reimbursed to them through the PHCN. CS-3 employs over 50 staff, who are on 24 hour shift. This power station is situated in the Niger Delta region of Nigeria and was established fully in the year 2010. The cost of the project for this power station is estimated at forty eight billion Naira (N48bn), which is about one hundred and sixty million pounds (£160 million). This cost includes the cost of site construction and equipment in the power plant such as gas turbine, laying of pipeline, and sub-station.

The power station currently receives frequent and regular maintenance of its equipment, as this is carried out by both foreign and local maintenance teams. The foreign maintenance team operation is carried out once every two years; while the local maintenance takes place on a quarterly basis and costs less.

4.5.1.2 Case Company Description

The primary operation of the organisation is electricity production. It generates a daily electricity of 150 MW (using a gas turbine known as ALSTOM GT13E2), which is transferred to the national grid to provide support to the national electricity generation capacity. Although the power plant has just a gas turbine for its operation, it has enough land mass to accommodate up to 5 more extra turbines, if they are made available. Fortunately, the case company receives its gas supplies directly from a nearby gas plant.

This case study aims to understand gas supply, gas utilisation and electricity generation from the power station. This case study company was chosen because the case company operates by conversion of gas to electricity as the primary technology for the management of flared gas.

4.5.1.3 Background of Participants

In CS-3, interviews were carried out on five (5) key personnel within the organisation. Table 4.7 highlights a brief background of the participants in the interview. The choice of these interviewees was based on the fact that the study intends to use the results from the interview as a guide to develop a framework for gas flare management, and with their sensitive and key positions, these interviewees were the best suitable to provide vital information. To this effect, the following key position with responsibilities were chosen and interviewed:

Power Plant Operator: The major responsibilities for this position include control of generator output to match the phase, frequency, and voltage of electricity supplied to panels; monitor and inspect power plant equipment and indicators against operational problems; regulation of the flow of power between generating stations and substations.

Operations and Maintenance Manager: Responsibilities include implementation of preventative maintenance programs; designing of maintenance programs; enforcing industry requirements; assessment of risks.

Electrical Maintenance Repairer: Installs and repairs any electrical equipment that develops faults in the site.

Technical Manager: Technical manager provides enabling working atmosphere to project teams and ensure objectives are met within stipulated time; provide direction and technical expertise in design, development and systems integration among other responsibilities.

Shift Supervisor: Responsibilities for this position include conducting employee performance reviews; supervision of production line operations in accordance with the electricity generation policies; mutual communication with the plant manager and train production line employees when necessary.

Table 4. 7: Brief Background for CS-3 Interviewees

Position	Gender	Year of Experience
Power Plant Operator	Male	10
Operations and Maintenance Manager	Male	5
Electrical Maintenance Repairer	Male	16
Technical Manager	Male	2
Shift Supervisor	Male	7

4.5.2 Presentation of Results from Case study company 3 (CS-3)

The results from Case Study Company 3 are discussed in this section based on five main themes as shown below:

4.5.2.1 Electricity production

Electricity generation in CS-3 is efficient and this could be linked to the fact that the power station is relatively new, with effective and modern equipment. 150 MW of electricity is produced daily. The power plant operator is of the opinion that *'this power station produced 150 MW of electricity daily as long as there is regular daily gas supply necessary to operate the gas turbine. Although in rare cases they experience shortage or even lack of gas supply which leads to reduction in electricity generation'*.

The power station is equipped with modern electrical facilities that help them monitor and control electricity production and transmission to the national grid through the PHCN. During the interview with the electrical maintenance repairer, he stated as follows *'we have a well-equipped technical control room with state of the art floweb control panel that helps us to monitor energy production, transmission and processes. If there is a fault with our generator, it is flagged up and we swiftly respond to avoid further damage. So as you can see, we are well prepared and equipped for electricity production in this power station'*. Pictures taken from the site and from the electrical control room during site observations are seen in Figures 4.9 and 4.10 confirming availability of state-of-the-art floweb and showing different sections of the floweb control panel in the company.

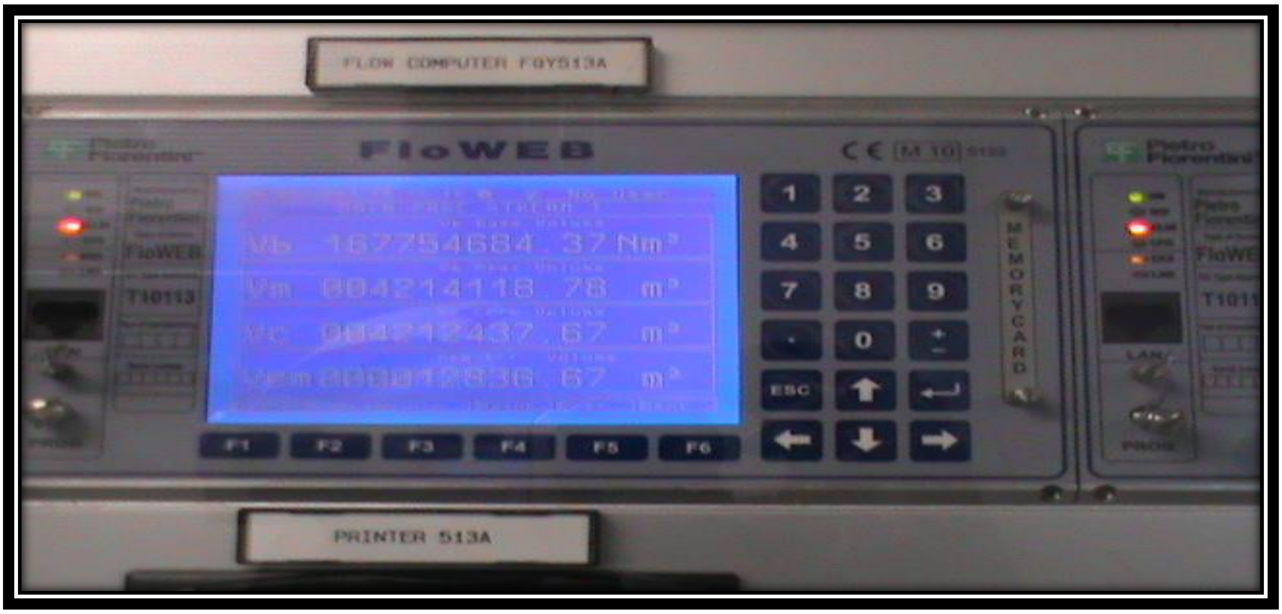

Figure 4. 9: A Section of Floweb Control Panel in the Control Room

Figure 4. 10: A Section of the Control Room showing Electrical Control Panel

4.5.2.2 Sources of Gas and Gas Utilisation by Turbine

The Gas Plant (CS-1) primarily supplies gas directly to CS-3 to operate the gas turbine that exists in the Power Station. This signifies that there is a direct linkage of pipeline between the gas station and this case company. It is worth mentioning that the distance between CS-3 and Gas Station is about 2.5 kilometers. On a daily basis, this power station receives and utilises 120 mmcmd of gas for the operation of its gas turbines.

There is therefore, regular supply of gas, however, on rare occasions, there could be a problem with the trunk line, which limits the supply of gas. As directly stated by the operations and maintenance manager *'in a situation whereby we experience a gas shortage or lack of gas, it is my responsibility to inform the power plant operator. When this is done, he now makes sure that the gas turbine is switched off before the gas is exhausted to avoid complete drainage of gas in the turbine's system.* Figure 4.11 shows a section of gas turbine in CS-3 highlighting the gas reduction/control section of turbine.

Figure 4. 11: Gas Reduction Section of a Turbine in CS-3

4.5.2.3 Typical Problems in the Power Station

CS-3 also has some operational problems as detailed below:

4.5.2.3.1 Lack of Local Trained Maintenance Team

This power station lacks capable maintenance team that could carry out a good and adequate maintenance on the station when necessary. According to the technical manager, the power station relies on a team of foreign experts for the major maintenance and servicing of the power station, particularly the planned maintenance operations that take place in the station: however, the operations and maintenance manager confirms that the power station still relies on a local maintenance team that is not well equipped for its minor and unplanned maintenance. This is risky, considering it could cause further harm to the equipment, although it cuts cost.

4.5.2.3.2 Irregular Gas Supply:

This problem arises due to sabotage on the gas line. If there is damage or a threat on the pipeline that connects gas to this power station, or a threat or damage to any of the pipelines associated with the Nigerian Gas Company (NGC) or the Gas Station, gas supply is automatically cut short by the gas station simply to avoid any form of hazard. For instance, *'in 2013, the gas pipeline witnessed a great problem and there was almost a fire outbreak when a group of vandals attacked the pipeline. They thought the pipeline was meant for conveyance of petrol, but unfortunately the content was gas. It caused gas leakage and the gas station was forced to shut production and supply of gas; this affected power station for over a week before the situation was rectified'*.

4.5.2.4 General Plant Condition and Maintenance

The general condition of the equipment in the power station was studied. It was gathered that the equipment are in good working conditions. Figure 4.12 highlights the route of gas to the gas turbine.

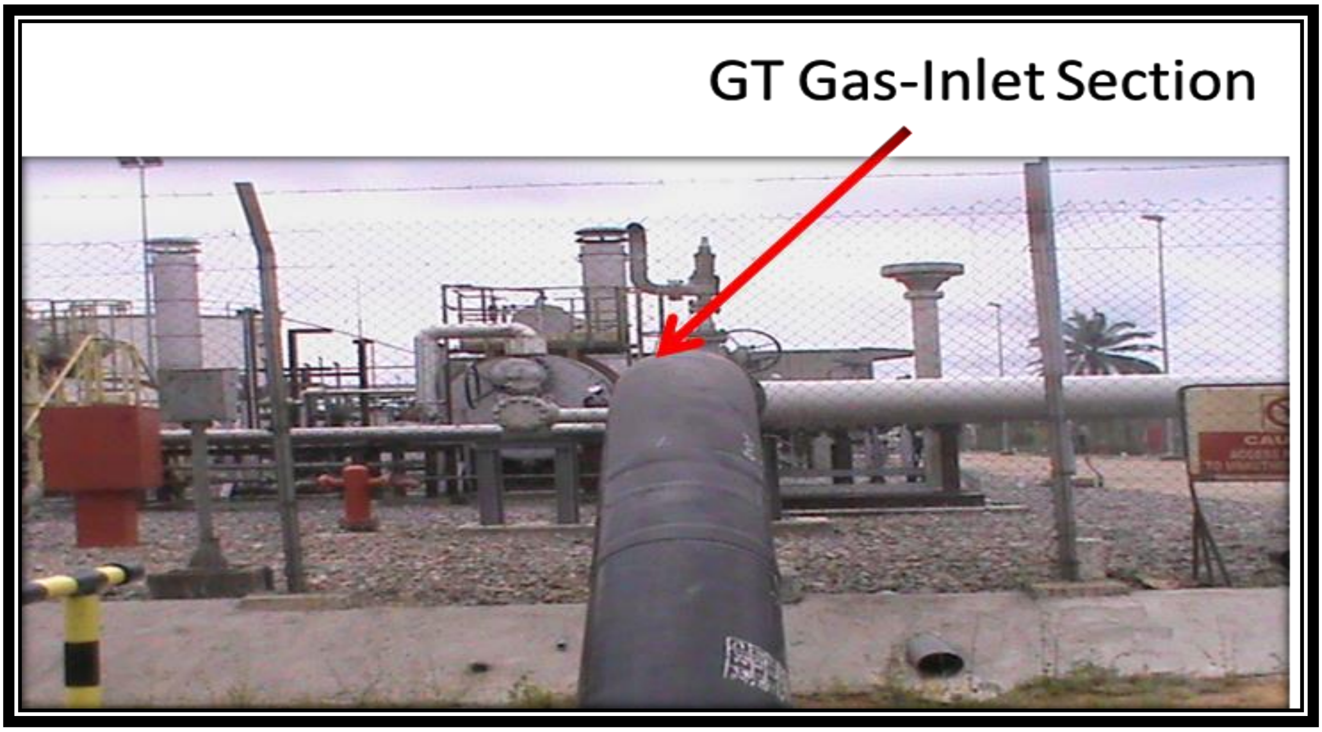

Figure 4. 12: Section of Gas Turbine showing the Gas Turbine-Inlet Section in CS-3

This study identified that maintenance is highly dependent on Equivalent of Operations Hour (EOH). The maintenance is divided into minor and major maintenances, both of which come after minor and major inspections respectively. When the operation and maintenance manager of the organization was interviewed concerning modes of maintenance, he stated categorically that *''the turbines have three levels of inspections (A, B, C). Levels A and B are pre-requisites to level C. This is because the level C inspections require real overhaul of the turbine parts, therefore they are dependent on A and B inspections. He confirmed that during A and B inspections, the maintenance team carefully monitors the situation of the various parts of the turbines such as blades, combustion chambers, burners, batteries as well as other parts to know their current situation; and in so doing, forecast or have an idea of what to expect in C inspection''.*

Each inspection comes after every nine thousand (9000) hours of use. Table 4.8 shows two stages of maintenance with 9000 EOH between each level of maintenance.

Table 4. 8: Maintenance types and timeframes in the power station

Level	A_1	B_1	C_1	A_2	B_2	C_2
Hrs	9000	18,000	27,000	36,000	45,000	54,000
Type of Inspection	Minor	Minor	Major	Minor	Minor	Major

4.5.2.5 Distribution of Electricity

This power station does not have total control of the utilisation of generated electricity; rather it is mandated to transfer its generated electricity to PHCN which, in Nigeria has the sole right to distribute electricity to end users. Therefore, CS-3 produces and transfers its generated electricity to PHCN through the national grid. The operations manager said *'we generate and transfer 150 MW of electricity daily to PHCN and we get a monetary value for that from them. We have an agreement on that, and so far both parties are fine with it. Although we will be happier distributing the electricity to the local communities within to help and improve the poor electricity scenario'*. It is worthy to note that even though there are two massive power plants within same locality in the Niger Delta region, it is sad to state that some communities within do not have electricity supply; in other words, these power stations have not positively impacted their lives.

4.5.2.6 Case study Summary

This case study helped this research to embrace the typical operation of a Nigeria thermal power station. This power station is constituted of one gas turbine of 150 MW capacity and transmits its generated electricity to the PHCN for further transmission to the end users. Although this is a newly constructed power station, it still has some challenges just like any other thermal power station in Nigeria such as irregular gas supply and lack of local trained maintenance team. Presently, this power station has a very effective maintenance culture which keeps the equipment in good condition as there is a regular minor maintenance every 9000 EOH and a major maintenance every 27000 EOH.

4.5.3 Chapter Summary

This chapter has analysed the data collected from one oil and gas company and two electricity producing companies used as case studies for this research. The results indicated that gas flaring is an active practice in the oil and gas industry in Nigeria. Although the oil and gas company tries to minimise gas flaring, the study identified that much effort has not been applied towards significant success. The electricity producing companies (CS-2 and CS-3) could provide support towards achieving a successful gas flare reduction; however, they are currently plagued with some challenges like lack of efficient gas turbines and financial capability to manage the power stations. Therefore, there is need for a framework to support the effective management of gas flare in the Nigerian oil and gas industry as well as for other countries affected by gas flaring. This study has provided and proposed an effective framework for gas flare management, as duly shown in the next chapter of this thesis.

CHAPTER FIVE: DEVELOPMENT OF A FRAMEWORK TO MANAGE GAS FLARING

5.1 INTRODUCTION

This chapter proposes a framework for the management of gas flare in an oil and gas environment in general, using Nigeria as case study. Concisely the chapter is sub-divided into 6 sections, with the first section discussing the concept and process of gas-to-wire. It also hinted on the gas turbine, with more concentration on the thermodynamics, with reference to some worked-out examples. In the second section of this Section, this study discussed the economic evaluation of gas-to-wire, with significant emphasis on the Nigerian context – the estimated capital investments as well as the estimated income statements were highlighted. In line with the above stated, the study also analyzed the tariff and pricing of electricity in Nigeria to understand the sources of income in the sector. The third section discusses the development of a framework that acts as a platform and precursor for the proposed framework for management of gas flare. In the fourth Section, this study developed a proposed framework for gas flare management. The framework represents the core aim of this study and is proposed to the oil and gas industry and electricity production industry. The framework primarily promotes minimization of gas flaring and improved electricity generation. The fifth Section represents the framework for gas flare management in the Nigerian context, with inputted figures. In the sixth section, this study highlights the reasons for the choice of GTW for the management of gas flare in Nigeria.

5.2 THE CONCEPT OF GAS-TO-WIRE (GTW) TECHNOLOGY FOR GAS FLARE REDUCTION

Electricity generation with power cycle is one of the methods for eliminating gas flaring. The basic principle of the power cycle requires burning gas in a gas turbine (GT) and producing power that can be converted to electric power by a coupled generator. This has been discussed in detail in chapters two of this thesis (sections 2.8.6). The technology of gas to electricity (gas to wire) involves a linkage of processes which include gas gathering and transportation system (which involves pipelines), processing plant, storage facilities (reservoir to contain gas), and the gas turbine for electricity generation. A flow chart that demonstrates this process from one stage to the next is shown in Figure 5.1. As a routine during oil exploration, the associated natural gas is mostly wasted either through flaring or venting. However, instead of wasting the gas, it could be gathered in a reservoir through pipelines. Subsequently, the gas is channeled to a power station for electricity generation. If the entire flare gas becomes excessive for electricity generation, the remainder could be channeled towards other technologies such as liquefied natural gas (LNG), gas to liquid (GTL) and gas to methanol.

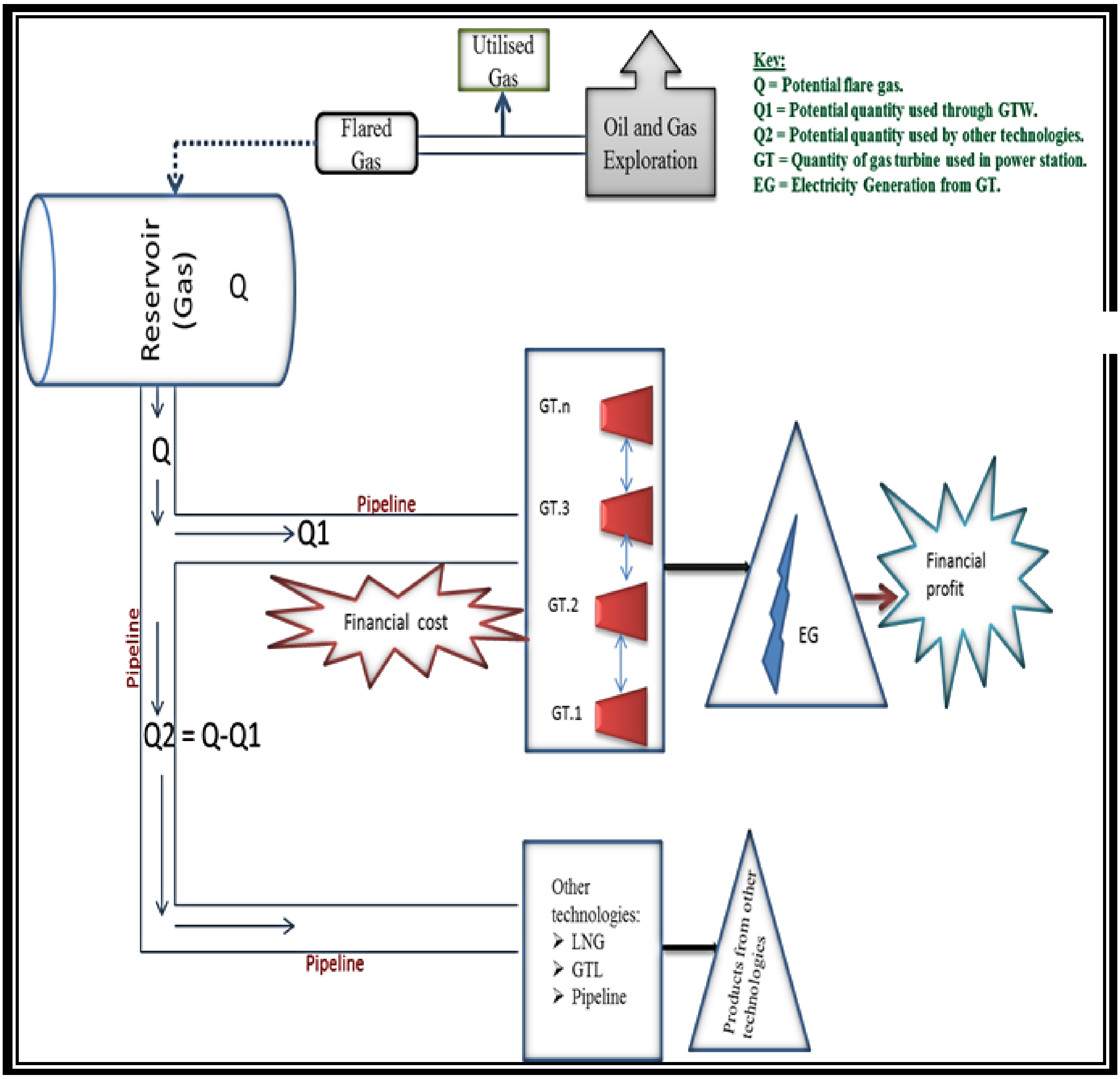

Figure 5. 1: Flow chart showing gathering and utilisation of flare gas

5.2.1 The Reservoir

The most common and important form of gas reservoir is the underground reservoirs, which basically are of three variants. These are known as depleted gas reservoir, aquifer reservoir, and salt cavern reservoir. Out of the above-mentioned three, the depleted reservoir formation is readily capable of holding injected natural gas. Using such a facility is economically attractive because it allows the re-use, with suitable modification, of the extraction and distribution infrastructure remaining from the productive life of the gas field which reduces the start-up costs. Depleted reservoirs are also attractive because their geological and physical characteristics have already been studied by geologists and petroleum engineers and are usually well known. Consequently, depleted reservoirs are generally the cheapest and easiest to develop, operate, and maintain. Figure 5.2 shows different types of underground reservoir, highlighting the depleted gas reservoir. According to Energy.Gov (2015), natural gas can be stored underground in five major different means and they include:

A: Salt caverns

B: Mines

C: Aquifers

D: Depleted oil/gas reservoirs

E: Hard rock mines

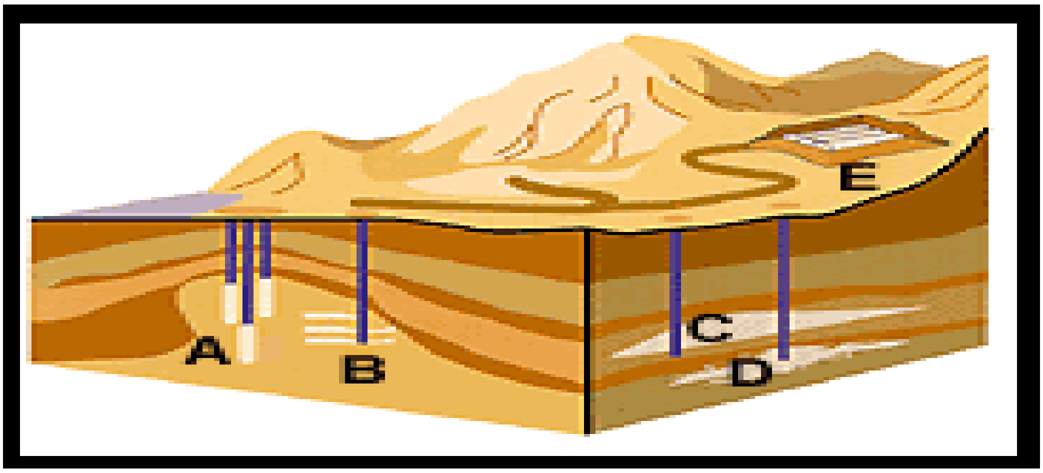

Figure 5. 2: Natural gas storage (Energy.Gov, 2015)

5.2.2 Transport System

This requires the use of pipelines as the mechanism to transport or move gas from production sites to final locations where it will be used as fuel for gas turbines for the generation of electricity. Basically this involves a pipeline system that starts at the natural gas producing well or field. Once the gas leaves the producing well, a pipeline gathering system directs the flow either to a natural gas processing plant or directly to the mainline transmission grid, depending upon the initial quality of the wellhead product.

According to Mohitpour (2003), gas pipelines are constructed from steel with inner diameter typically from 4 to 48 inches (100 to 1,220 mm). Most pipelines are typically buried at a depth of about 3 to 6 feet (0.91 to 1.83 m). To protect pipes from impact, abrasion, and corrosion, methods such as wood lagging, concrete coating, rock shield, high-density polyethylene, imported sand padding, and padding machines are applied. A real-life pipeline system is shown in Figure 5.3, describing the transportation of gas from one location to another.

Figure 5. 3: A real-life gas pipeline system

This research identified two ways that this should be done, namely the single gathering method and the multiple gathering method. This process enabled this study to realise the best suited option for the gas flare management using GTW

5.2.2.1 Single-Gathering Method

In this method, the natural gas is harnessed from a single processing site (well head), and channelled to the gas reservoir tank through the pipeline, for onward usage as fuel for the turbines (fixed on-site) for the generation of electricity. Figure 5.4 shows an example of how this works.

Figure 5. 4: Single gathering method

5.2.2.2 Multiple-Gathering Method

This method requires the natural gas to be harnessed from two or more processing sites (well heads) and used as fuel for the turbines for the generation of electricity. This requires using pipelines as link for all the well heads (which are the sources of gas) and the reservoir. The reservoir supplies gas to a power station which is stationed within. This method will guarantee the gathering of more volumes of gas because of multiple sources; however, it requires more financial investment. A schematic of this method is shown in Figure 5.5. This method is better suited for Nigeria because its gas reserves are scattered all over the Niger Delta region. It also guarantees steady gas supply. This is because gas gathering is from more than one source, which makes it difficult to experience unavailability of gas due to lack of exploration from a site.

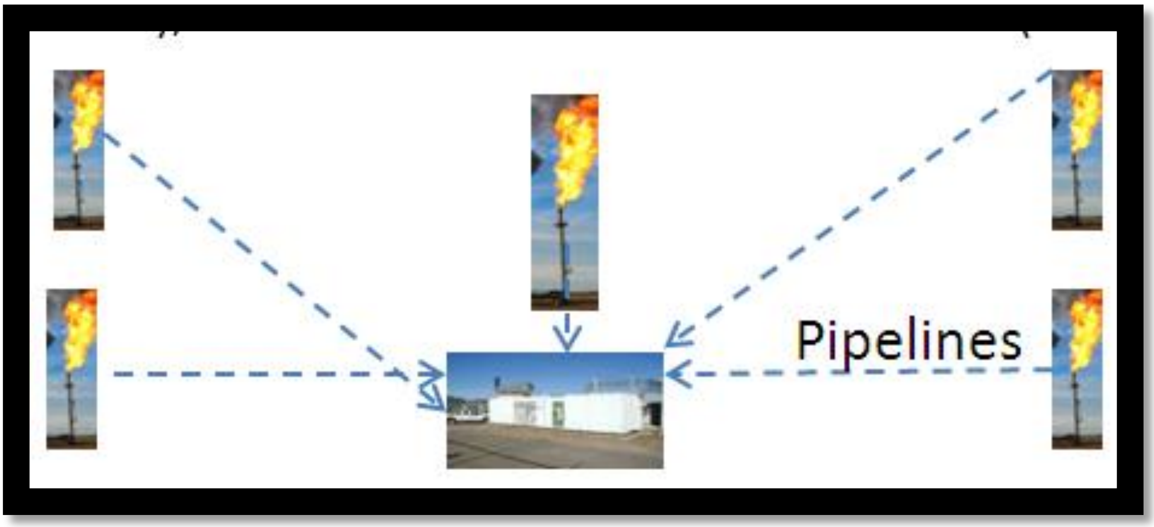

Figure 5. 5: Multiple gathering method

5.3 ECONOMIC EVALUATION OF ENERGY GENERATION THROUGH GAS-TO-WIRE IN NIGERIAN CONTEXT

Having discussed the operations of a turbine, it is essential to assess the financial implications of the application of GTW for the management of gas flaring. This assessment considered the expenditures and incomes from sales of electricity.

Functional gas turbines in the power station are a vital prerequisite for long term existence of a power station project. Maintenance is essential for electricity generation in a power station. Therefore, the economics of the GTW technology was also carried out in this study to identify the cost and effect associated with the project in entirety such as cost/maintenance of gas turbines. Other considerations that facilitated the evaluation of the economic assessment of GTW technology for gas flare management include the daily volume of gas consumption by the units of gas turbine, the estimated capital investments, as well as estimated financial income from sales of electricity. The economic assessment explicitly identified the cost and effect of using gas turbines and volume of potential flare gas necessary for the production of electricity in the case study. However, the same process can still be applied to any other country which has the same problem of routine gas flaring.

The economic evaluation on GTW technology was carried out using a gas turbine known as ALSTOM GT13E2, which has a capacity of 150 MW. Its primary performance parameters are shown in Table 5.1 (highlighting particularly the gross electricity output, thermal efficiency, turbine speed, fuel gas temperature and frequency). This framework of gas turbine was chosen because it has a good performance level (ALSTOM, 2010), and it is currently in use in some power stations in Nigeria.

Table 5. 1: Primary performance parameters for GT13E2 (ALSTOM, 2010)

Fuel	Natural Gas
Frequency	50 Hz
Gross Electricity Output	150 MW
Gross Electricity Efficiency	36.4%
Thermal Efficiency	36%
Turbine Speed	3000 rpm
Exhaust Gas Flow	537 kg/s
Fuel Gas Temperature	31 ^{o}C

- The economic evaluation is based on the assumption that the availability and consistency of the gas turbine (in terms of being in good working condition) is 100% throughout the year (i.e., the plants operate for 365 days of the year).
- It was further assumed that the units of gas turbine operate at full power capacity, which is 150 MW daily, and selling all the produced electricity to the national grid.
- It is also worthy to reiterate that this economic assessment is based on 50 units of gas turbine putting into consideration the annual volume of gas flare in Nigeria.
- Calculations for break-even point capacity (B.E.P), product cost for plant, yearly income in B.E.P capacity, total yearly income, gross profit, net profit and rate of return (ROR) were done using equations 1 – 7 (Peter and Timmerhaus, 1991).

- ✓ Also the study considered the estimated total electricity need of Nigeria and current electricity production in Nigeria as shown Table 5.2. This was also instrumental for the adoption of 50 units of gas turbine for this calculation.

Table 5. 2: Estimate of energy demand and supply in Nigeria.

Estimated Electricity Requirement in Nigeria	Total Electricity Production	Extra Electricity Needed
12,000 MW	4,358 MW	7,542 MW

5.3.1 Estimated Capital Investment in a Typical Nigerian Power Station

Data for turbine installation and maintenance were obtained from Case Study Companies' (CS-2 and 3) documents and also from research carried out elsewhere (Rahimpour *et al.*, 2013 and NREL, 2012).

- Equipment (Turbine): This includes the cost of acquiring a gas turbine with a capacity of 150 MW. This also covers the cost of transportation from point of sale to site or power station. According to Peters and Timmerhaus (1991), this could also include accompanying spare parts, equipment allowance and inflation cost.

- Piping and installation of equipment: When a new gas turbine comes to the power station, it needs to be properly installed before being put into use. Therefore the cost of piping and installation includes labour, valves, fittings, pipes, supports as well as other items that are associated with the complete erection of all piping used directly in the procedure (Peters and Timmerhaus, 1991). This also involves the installation of electrical equipment.

- Royalty to Community: This accounts for the monetary compensation given to the host communities of the power station. It compensates for the piece of land, access road to the power station, as well as the potential noise and environmental pollution that may arise as a result of the operations in the power station.

- Working cost/maintenance: For the power plant and the operating equipment to be in good and efficient operational conditions, there is need for an amount to be budgeted for operation and maintenance. This refers to the financial cost of running the power station to ensure smooth operation of activities. This covers the routine maintenance, cost of labour, materials and supervision within the power station. According to Peters and Timmerhaus (1991), the annual maintenance ranges from 2 percent to 20 percent of cost of equipment depending on the equipment.

- Pipeline Costing: Pipeline as a means of gas transportation has been described earlier in this Chapter (Section 5.2.2). The financial implication is not included in the buildup of the framework for gas flare management for some obvious reasons. Pipeline projects are evaluated based on the distance it covers (mile or kilometer) as well as the diameter. Therefore making a financial estimation could be based on the distance from the gas stations to power stations (with regards to the recommended 'multiple gas gathering system'), as well as the diameter of the pipeline itself (measured in millimeter). Generally, in construction of pipelines, the materials and labour consumes about 80% of the total construction cost (Adamu et al., 2015). The remaining 20% goes towards miscellaneous (surveying, supervision, engineering, administration, taxes, freight, telecommunication equipment etc) and right-of-way (R.O.W.) and damages.

  However, it is worth noting that the costs could increase if the pipelines go through residential areas, or there are roads, highways or even rivers. In addition, costs depend on locations, terrains, population density as well as other factors such as tas laws and labour as may be operated in various countries. For instance, according to SweetCrude (2017), natural gas pipeline construction costs vary between US$ 800,000 (£600,000) to US$ 2 million (£1.6 million) per km (for large diameter projects over rugged terrain). In the Nigerian context, it could be difficult to precisely factor in the cost implication of pipeline because gas stations and flared gas sites are irregularly scattered over the Niger Delta, and as such, it is more difficult to identify the distance from the flare site/gas station to the power station.

Therefore, with regards to the framework for flared gas management, it is good to note that the financial profit from the use of GTW for flare gas management could further be affected adversely when the cost of pipeline is factored in.

- Total capital investment: This is a summation of all the financial investments in a Nigerian power station involving 50 units of gas turbine with a total capacity of 7500 MW.

Table 5.3 presents a statement for the estimated capital investment for the generation of 7,500 MW of electricity in Nigeria and this is based on 50 units of gas turbine with single capacity of 150 MW. Some costs are yearly occurrence, while others are one-off costs.

Table 5. 3: Typical Estimated Capital Investment Report for a Nigerian Power Plant (Data from Case Studies 2 and 3; Rahimpour et al., (2013); NREL (2012); Peters and Timmerhaus, (1991))

DESCRIPTION	COST (£)
Equipment (50 Units of Gas Turbine)	1,051,575,000 (140.210/kw)
Piping and installation of equipment	360,900,000
Royalty to Community	100,000
Working cost/Maintenance	230,610,000/year
Total capital investment	1,643,185,000

5.3.2 Estimated Electricity Generation and Financial Output from a Typical Gas Turbine in Nigeria

The residential tariff system is the most commonly used in Nigeria. Therefore, it was utilised as a basis for the calculation for income from sales of electricity. A kWh of electricity costs £2.80 as identified from documents of case studies companies 2 and 3. Based on this cost of electricity, a calculation is provided to demonstrate the financial output from a 150 MW capacity turbine.

First, it is good to re-emphasise the volume of gas that a unit of gas turbine can utilise. Typically, a unit of ALSOM GT13E2 framework utilizes a flow rate of 930,000 m^3 of gas per day as established from investigations carried out in a typical Nigerian power plant. Therefore, on a yearly basis, a unit of gas turbine consumes 930,000 X 365 (339,450,000 m^3). It is now possible to establish the estimated potential annual income from the electricity that is generated from a unit of gas turbine in Nigeria, based on ALSTOM GT13E2. This is shown in the calculations below:

1 MW = 1000KW

Converting gas turbine capacity of 150 MW to KW:

[150 X 1000 = 150,000]

Cost of electricity per KWh in Nigeria = £0.07 [where £0.07 is the cost of electricity per kilowatt hour]

Therefore to calculate the financial income:

150,000 x 0.07 = £10,500 (per day)

Therefore yearly income per unit of 150 MW turbine` = £10,500 x 365 = **£3,832,500**

5.3.3 Estimated Financial Income from a Typical Nigerian Power Plant

The calculation in Section 5.3.2 above demonstrates the financial income from a gas turbine of 150 MW capacity in a typical power plant in Nigeria. The total cost for sale per year is the income from sales of electricity generated annually from the 150 MW gas turbine. Operators' tariff is the income generated as a service charge, which is billed on the electricity distribution firms. In the course of carrying out the estimated financial income, several variables were considered and they include as follows:

i. Break-even point: This is the point where the total cost of electricity production equals the total income from energy sales.

ii. Direct Production Cost: This includes expenses directly associated with the manufacturing operation. This consists of expenditures on direct operating labour; supervisory and clerical labour directly connected with the manufacturing operation; plant maintenance and repairs; operating supplies; power; utilities; and royalties.

iii. Fixed charge: This includes fixed expenses from year to year and do not vary widely with changes in production rate. This includes property taxes, insurance and depreciation.

iv. Total product costs: This study adopted the annual mode of calculation because according to Peters and Timmerhaus (1991), the annual cost basis is probably the best choice when estimating total cost because of four major reasons:

(1) The effect of seasonal variations is flattened out.

(2) Plant on-stream time or equipment operating factor is considered.

(3) It permits more-rapid calculation of operating costs at less than full capacity.

(4) It provides a suitable way of considering irregularly occurring but large expenses such as annual turnaround costs in a refinery, and in this case, a power plant.

v. Capacity of unit per year: This categorises the overall amount of electricity generated by a specified unit of gas turbine per year; in this study, 50 units of gas turbine are utilized in a year. This is measured in kW.

vi. Total Cost: Total Capital Investment + Fixed Charges + Total Product Cost for Turbine Operation/ year.

vii. Total Yearly Income: Shows all incomes into the power plant resulting from sales of electricity on an annual basis. This is calculated before the extraction of taxes.

viii. Gross Profit: This is the total financial income from sales of electricity minus the cost of production of the electricity.

ix. Net Profit: This is the actual profit after working expenses have been deducted.

It is worthy to note that the calculations for break-even point capacity (B.E.P), product cost for plant, yearly income in B.E.P capacity, total yearly income, gross profit, net profit and return of investment (ROI) were all carried out using equations provided by Peters and Timmerhaus, (1991) and Trading Economics (2016). These are stated as follows:

- Cost of sale of electricity x B.E.P capacity = Cos of operation x B.E.P capacity + fixed charge.
- Product cost for turbines operation = Direct Production Cost ÷ Plant Capacity.
- Total product cost from turbines/year = Product cost for plant x total production x 24 x 365
- Break-even point (B.E.P) capacity = Fixed charges/product cost for sale – product cost for plant.
- Capacity of unit per year = Unit of gas turbine (kWh) x 365.
- Yearly income in B.E.P Capacity = Break-even point capacity x Cost of sale of electricity
- Total Yearly Income = Capacity of Unit per year x Cost of sale of electricity.
- Total Cost = Total Capital Investment + Fixed Charges + Total Product Cost for Turbine Operation/ year
- Gross Profit = Total yearly income – Total Cost.
- Net profit = 0.7 (tax of 30%) x Gross profit
- ROI = Annual Profit ÷ Capital Investment x 100.

The product cost for sale is the retail cost of electricity per kWh. Total product cost for sale is the financial value of the all generated electricity, and this also represents the total yearly income. Product cost for plant is the cost of electricity generation per kWh. To determine the net profit, 30% corporate tax, which, is applicable in Nigeria, was applied (Trading Economics, 2016). Table 5.4 has shown a potential financial income from investment in GTW in Nigeria.

Table 5. 4: Estimated Income and Return Statement for a Typical Nigerian Power Plant

Caption	Value
(a): Cost of sale of electricity	£0.07/kwh
(b): Total cost of electricity sale/year	£4,599,000,000
(c): Product Cost for turbines operation	£0.007/kWh
(d): Total product cost for turbines/year	£459,900,000
(e): Fixed Charges	£689,850,000/Year
(f): Break-even Point Capacity	10,950,000,000 kWh
(g): Yearly income in B.E.P Capacity	£766,500,000
(h): Capacity of turbines Per Year	65,700,000,000 kWh
(i): Total Cost	£2,792,935,000
(j): Total Yearly Income	£4,599,000,000
(k): Gross Profit	£1,806,065,000/year
(l): Net Profit	£1,264,245,500/year
(m): ROI	16.3%/year

Typically, as has been established in this study, particularly from the economic assessment, the cost and effect of using GTW as a means for gas flare management, typically in Nigeria has three significant implications:

i. Huge amount of finance is required for investment. This goes primarily towards the capital investment as specified earlier in Section 5.3.1 and Table 5.3. Typically, for a Nigerian power plant that will potentially accommodate 50 units of ALSTOM GT13E2, one billion, six hundred and forty-three million, one hundred and eighty-five thousand pound (£1,643,185,000) is required as an estimated capital investment.

ii. Financial outcome. On a yearly basis, the investment potentially generates a net profit of two billion, six hundred and eighty two million, seven hundred and fifty thousand pounds (£1,264,245,500). This high level of profit could be attributed to three major reasons:

(a) Cost of electricity in Nigeria (£0.07 per kWh).

(b) Very high amount of electricity produced from the turbines.

(c) High demand of electricity in Nigeria.

iii. The period of return on investment. For the Nigerian scenario and with 50 units of gas turbine, the return on investment period is about 6 years (100/16.3% = 6.1 years). This is a positive motivation for potential investors because recuperation of the capital investment does not take a very long period of time.

To ensure the potential investment in the gas flare management framework is financially viable over its period of operation, a financial appraisal of the framework was conducted taking into consideration the amount of investment (money) required to get the project set up and the financial returns expected from the institution of a gas flare management framework. Different financial investment techniques were considered for this project and discounted cash flow techniques such as Net Present Value and Internal Rate of Return (IRR) appeared more appropriate as the basis for appraising this project.

After consideration of the two techniques, the NPV was deemed more suited to this project and was used to determine the present value of cash flows associated with setting up a gas flare management system, which would use GTW as the basis for managing the flared gas. As a technique for discounting cash flow, the NPV of a project or investment reflects the degree to which cash inflow equals or exceeds the amount of investment capital required to fund it. In the case of this framework, the NPV is used to calculate the profitability of using GTW as a means to manage the flared gas in Nigeria.

Microsoft Excel was used to aid the calculation of the Net Present Value of the investment into the GTW technology. The formula for NPV calculation used was:

NPV = Σ {Net Period Cash Flow/(1+R)^T} - Initial Investment

- Where R is the rate of return, and T is the number of time periods.

For this calculation, T is assumed to be 6 years, which is the return period based on the calculation in table 5.4. R is taken to be 14% based on the bank rate as at the time of this research (Trading Economics, 2017).

To get the net returns for the six years in question, assumptions were made for years 2 to 6. It was assumed that the production capacities of the turbines would reduce as the years progressed and maintenance costs could also increase leading to decrease in the net profit. Subsequently, it was therefore assumed that the net profits would reduce by about 2.4% yearly. For this reason, the following net profit figures were achieved, as could be seen in Table 5.5 below.

Table 5. 5: Net income for 6 years of investment

Year	Net Profit
1	£1,264,245,500
2	£1,233,903,608
3	£1,204,289,921
4	£1,175,386,963
5	£1,147,177,676
6	£1,119,645,412

The net present value calculations were made using the assumptions made above. The result of the NPV calculations is shown in the Table 5.6 below.

Table 5. 6: Net Present Value calculation for the project

			Interest 14%
Year	Cash Flow	Present Value	
0	-1,643,185,000	-£1,643,185,000.00	
1	£1,264,245,500	£1,108,987,280.70	
2	£1,233,903,608	£949,448,759.62	
3	£1,204,289,921	£812,861,394.20	
4	£1,175,386,963	£695,923,439.24	
5	£1,147,177,676	£595,808,137.46	
6	£1,119,645,412	£510,095,387.86	
Net Present Value		£3,029,939,399.08	
Internal Rate of Return (IRR)		71.97%	

From the analysis, it was identified that discounting the value of the investment and the yearly returns shows the framework is viable as the returns over six years show a high and positive Net Present Value amount. The internal rate of return was also used to check the level of interest rate at which it will be best investing in a different project instead of this current framework. The results indicate at it is only at an interest rate of 71.97% that another project will be more viable than embarking on this project based on the framework. From the calculations, it can be identified that the project is very viable and the investments into the framework would be justified.

5.3.4 Sensitivity Analysis

Sensitivity analysis was carried out to determine the potential changes and errors in the calculation of the economic viability of the proposed framework and their effects on the viability of the project. As suggested by Fiacco (1983), “a sensitivity and stability analysis should be an integral part of any solution methodology. The status of a solution cannot be understood without such information." In this section, a sensitivity analysis is carried out taking into consideration the different variables that are likely to have an effect on the outcome of the framework should they change or their real life values be different from the assumptions used in the calculations for this framework.

Sensitivity analysis was also carried out to check the risks associated with the use of the framework for gas flare management. Factors that were analysed for the purpose of this research are: availability of flared gas (in terms of capacity); sale price for electricity in Nigeria; production capacity of turbines; cost of turbine operation; and total revenue. For the purposes of sensitivity analysis, the impact of these factors on the level of net income to be generated from the project is calculated.

Results from the sensitivity analysis are provided below based on data from Table 5.4.

Table 5.7 highlights the impact of income from the project (revenue). It shows a sensitivity level of -10%, -5%, 5%, and 10%. A decrease of -10% from the revenue (which could be attributed to reduction in electricity production) as stipulated in the framework (£4,599,000,000) will result to significant decrease of 25.46% on the net profit of the project. Therefore, a -10% decrease on the revenue will be sensitive to the project in terms of net profit. Subsequently, with an increase of 5% or 10% comes improvement on the net profit. For instance, an increase of 5% on the revenue could improve the net profit by 12.73%.

Table 5. 7: Effects of Revenue Modification on Net Profit

	Revenue	Net Profit
Sensitivity		£1,264,245,500.00
-10%	£4,139,100,000.00	£942,315,500.00
-5%	£4,369,050,000.00	£1,103,280,500.00
0%	£4,599,000,000.00	£1,264,245,500.00
5%	£4,828,950,000.00	£1,425,210,500.00
10%	£5,058,900,000.00	£1,586,175,500.00

Table 5.8 demonstrates the impact of cost of electricity on the net profit of the project. This highlights variations of sensitivity levels of -4%, -2%, 2%, and 4% for £0.067, £0.069, £0.071 and £0.073 respectively. The original cost of electricity per Kwh is £0.07, so a decrease of 4% (£0.067) on electricity price is estimated to create a loss on the net profit to about 10% as shown on the right hand side column of Table 5.8. Subsequently, an increase on the cost of electricity causes an increase on the net profit. This is highlighted when the cost is increase by 4% of the original price. This increase also demonstrated a 10.18% increase to the net profit as could be seen in the table too.

Therefore, an increase or decrease of 4% to -4% on the cost of electricity in Nigeria is positively or negatively sensitive (as the case may be) to the net profit of the project.

Table 5. 8: Effects of Cost of Electricity Modification on Net Profit

	Cost of Electricity	Net Profit
Sensitivity		£1,264,245,500.00
-4%	£0.067	£1,135,473,500.00
-2%	£0.069	£1,199,859,500.00
0%	£0.07	£1,264,245,500.00
2%	£0.071	£1,328,631,500.00
4%	£0.073	£1,393,017,500.00

From Table 5.9, four different levels of percentage variations such -10%, -5%, 5% and 10% (£0.0063, £0.0067, £0.0074 and £0.0077 respectively) were applied for the sensitivity analysis to confirm the impact of change on the cost of turbine operation on the net profit of the project. A reduction or increase on cost of turbine operation creates either an increase or decrease to the net profit; thereby signifying that as times goes by, the net profit will start declining. This is because as time goes by, there will be need for higher repairs as well as change of spare parts due to wears and tears associated with use of equipment.

Table 5. 9: Effects of Cost of Turbine Operation Modification on Net Profit

	Cost of Turbine Operation	Net Profit
Sensitivity		£1,264,245,500.00
-10%	0.0063	£1,296,438,500.00
-5%	0.0067	£1,280,342,000.00
0%	0.007	£1,264,245,500.00
5%	0.0074	£1,248,149,000.00
10%	0.0077	£1,232,052,500.00

The capacity of turbines has a significant impact on the revenue of a power station. Therefore, a higher capacity signifies greater financial income. However, to identify the sensitivity of this variable (turbine capacity) with regards to the framework developed in this thesis, sensitivity level of 10%, 5%, -5%, and -10% were applied as shown in Table 5.10 below. A decline in the turbine capacity of up to -10% reduces the capacity from 65,700,000,000 to 59,130,000,000, and will lead to reduction of about 22.91%% on the net profit; while an increase of 5% (68,985,000,000) will raise the net profit of the project with about 11.45%. Therefore, to a great extent, turbine capacity is very sensitive to the net profit, particularly with regards to flared gas management with GTW technology.

Table 5. 10: Effects of Turbine Capacity Modification on Net Profit

	Turbine Capacity (kWh)	Net Profit
Sensitivity		£1,264,245,500.00
-10%	59130000000	£974,508,500.00
-5%	62415000000	£1,119,377,000.00
0%	65700000000	£1,264,245,500.00
5%	68985000000	£1,409,114,000.00
10%	72270000000	£1,553,982,500.00

5.4 GUIDANCE FOR THE DEVELOPMENT OF GAS FLARE MANAGEMENT FRAMEWORK

Prior to achieving the aim of this research which entails the development of a gas flare management framework, this study opted to develop a framework, which would act as a platform for the achievement of the gas flare management framework. The Decision Tree Process is a framework that has proved to be a success for gas flare reduction in Alberta, Canada. Therefore, this study also embraced and incorporated the Decision Tree Process towards the development of a framework for the development of a gas flare management framework. The Decision Tree Process led to the consideration of the Processes of Gas Flare Management that is being considered. Furthermore, the Legislative Framework, Monitoring/Enforcement Process, Policy and Partnership in Nigeria were all considered to make this framework a success.

5.4.1 Decision Tree Process for Gas Flaring and Venting

This research adopted and accommodated the solution gas flaring and venting "Decision Tree Process" that was recommended by Clean Air Strategic Alliance (CASA), as shown in Figure 5.6. CASA was established in 1994 as a new way to manage and improve the quality of air in Alberta, Canada.

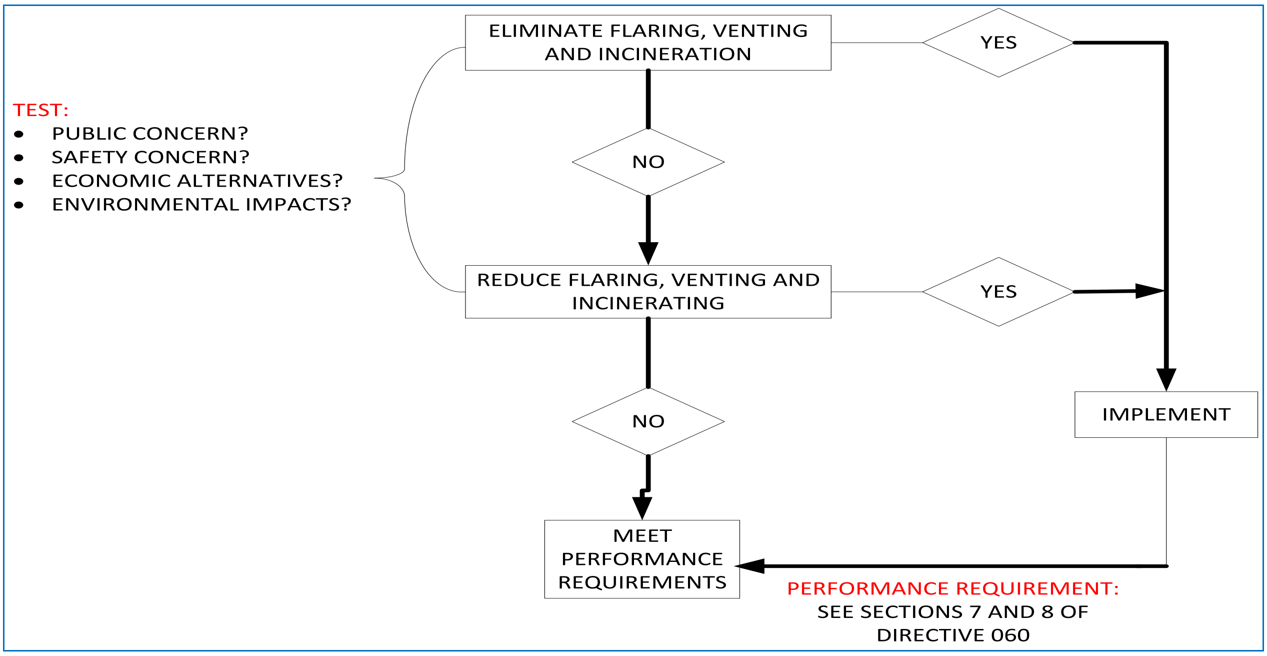

Figure 5. 6: Decision tree process Gas Flaring and Venting (ERCB, 2013)

Adoption of the Decision Tree Process is based on the fact that it has proved to be a success in Alberta, which is a region known for huge gas deposit and production in Canada. The region was synonymous with gas flaring, but after the introduction and adoption of the Decision Tree

Process, gas flaring has become a non-significant act. In the Nigerian situation, gas flaring is so high that more than half of the yearly gas production (18.27 BCM) is flared. Therefore, with the modification and application to the Nigerian scenario, this will prove a significant measure to the management and reduction of gas flaring.

The Decision Tree Process states that gas flaring and venting should be eliminated basically due to the environmental impacts associated to the process; but if total elimination is not realistic, it should be reduced to barest minimum. However, in a situation that neither elimination nor reduction could be met, the performance requirements as stipulated in section 7 of the Directive 060 must be met.

According to Section 2 of the Alberta's tool for regulating flaring (Guide 60), if gas utilization is economic (based on incremental economics for gas), the operator needs to proceed with the utilization of gas rather than flare the gas. However, if utilization is uneconomic, the operator is thereby permitted to flare the gas, although the flaring process must adhere to some stringent rules too. There are also clustering requirements whereby multiple facilities (wells, pipelines) that are in close proximity must be considered. While conserving gas at an individual well may not be economic, it may be feasible if multiple wells are tied together. Giving consideration to clustering is required by Guide 60, and also applies in cases where multiple operators are involved.

With regards to managing routine gas flare, there are three major processes that should be analyzed, and afterwards, the best suitable for the scenario in view is chosen and implemented. These options are referred to as elimination, reduction and continuous flare. These are discussed in more details in the subsequent paragraphs. However, it is worth mentioning that this concept is taken from the Decision Tree Process for solution gas flaring and venting, which is discussed directly below.

5.4.1.1 Process of Gas Flare Management

- Elimination of gas flare: This involves the total termination or stoppage of non-associated gas, otherwise known as solution gas. The significance of this process is that gas flare reduction will improve because the potential source of flaring will only come from associated gas. In this process, with regards to the framework in this research, the operators meet with the energy/electricity generation firm(s), for example Power Holding Company of Nigeria (PHCN) and other Independent Power Providers (IPPs) in Nigeria. The electricity demand and availability in the country will be discussed to know exactly what is expected to satisfactorily sustain the country in terms of megawatt of electricity (MW). The estimated available gas to sustain such production through gas turbines will be discussed, as well as the total units of gas turbine needed. In the Nigerian context, total elimination of gas flaring may be very difficult to achieve. This is due to the fact that one of the reasons for gas flaring is for safety purpose during crude oil production. Therefore, it will be very difficult to totally eliminate gas from being flared.

- Reduction of gas flare: If it is not possible to totally stop the flaring of gas (both non-associated and associated gas) during crude oil and gas exploration and production due to health and safety reason or for any reasons, then at least the volume being flared could be minimized. In this process, which mostly involves both the associated and non-associated gas, the operators are required to conform to stipulated standard flare performance requirements, which includes health and safety, as well as the environmental impact. Subsequently, just as in the gas elimination process, the oil and gas operators will meet with the energy/electricity generation firms and discuss as stated in the framework in this study.
- Continuous flare: In rare situations whereby the gas flare could neither be eliminated nor reduced, due to reasons ranging from difficulty to harness gas because of distance or because of lack of infrastructure, there is a rare option for continuous flare. However, the Operator MUST comply with the implementation of voluntary standards for gas flaring (Ellis, 2016) which entails the elimination or reduction of the potential and observed impacts of these activities and to ensure that public safety concerns and environmental impacts are addressed before beginning to flare. It is also worth mentioning that this option will not come without a huge penalty. In other words, the operators are indirectly told to provide a means to manage gas flaring or the face the consequence – huge financial fine. In this process, this framework is not virtually stating and authorizing the operators to continue to flare gas. Rather it understands the drawbacks that the oil and gas industry could face, particularly in developing countries as well as the complications in extraction of associated gas. In this scenario, the situation and current practices are

required to be reviewed by the management of the operators and then reduction machineries be put in motion, to facilitate at least some form of gas flare reduction. Afterwards, the pattern followed in the REDUCTION process is utilized.

5.4.2 Policy and Partnership

In this process and situation, the Nigerian government shall be proactively involved. The government's involvement is through the promulgation of policies that could attract some more private investors and also motivate the existing oil and gas operators. That is what this research refers to as 'Policy and Partnership'. This is expected to create a different point of view for the operators on how they handle the 'flared gas' (Change in Perception). The policies will accommodate both incentives as well as penalties. This is more like the "carrot and stick approach", whereby offenders are punished accordingly through heavy financial fine, so as to deter them from subsequent acts; while adherers are compensated squarely. The incentives will come in the forms of tax holidays and reductions, as well as guaranteed bank loans where necessary, reduced bank interest rates on loans; while penalties will be charged on any operator who flares more than the stipulated minimal volume of gas. The incentives encourage operators to utilize gas and this could require acquisition of huge reservoirs for gas gathering. Gathered gas will be utilized as fuel for gas turbines, which in turn generate electricity, for internal usage, external usage or for both internal and external usages. For a successful project, the electric power sector will also need to be included as stakeholders. In Nigerian scenario, this involves Power Holding Company of Nigeria (PHCN) and other Independent Power Producers (IPPs) who are responsible for most of the electricity generation and solely in charge of national electricity distribution.

5.4.3 Legislative Framework

Studies by other researchers have shown that gas flaring is arguably the biggest problem that the Nigerian oil and gas industry faces due to its associated impacts (Oloruntegbe *et al.*, 2009; Kalio-Danial and Braide, 2006; Osuaka and Roderick, 2005). However, it is unfortunate that Nigeria lacks an effective legislation as well as stringent sanctions that are needed to fight this menace (Hassan and Kouhy, 2013). Although this inadequacy is linked to the fact that oil and gas, or more specifically crude oil is responsible for the sustainability of the Nigerian economy;

thereby making the government to view the waste of associated gas and the environmental degradation associated with gas flaring as trivial issues.

It is worth mentioning that the government over the years has attempted to control gas flaring by setting up legislations to stop and regulate the act by oil and gas industries (Ukala, 2011; Ishisone, 2006). In theory, routine gas flaring was outlawed in Nigeria in 1984, through the Section 3 of Nigeria's Associated Gas Reinjection Act 1979, however, the practice has continued persistently till date (The Guardian, 2015). Its ineffectiveness is hinged on the fact that the penalty associated with the sanction for flaring is not huge, thereby providing an escape route to the oil and gas operators and as such giving them the opportunity to choose the "flare and pay" option. Again, no framework is in place to monitor the volume that these operators flare; rather whatever volume the operators tell the government is what the government believes. This has been a huge economic loss considering the fact that in recent years, the oil companies in Nigeria pay an annual fine of about US$150,000 – 375,000 for flaring gas, whereas the country loses about US$2.5 billion on gas flaring.

Therefore, the problem is not the enactment of bills/law, but the provision of stringent penalty, and also the availability of enforcement mechanism. Therefore, the framework in this study, while soliciting for stringent legislative framework also encourages for effective monitoring process to keep abreast the activities within the oil and gas operations in Nigeria.

Some existing Nigerian legislations on gas flare management include:

- Petroleum Act and the Petroleum (Drilling and Production Regulations) 1969.
- Associated Gas Re-injection Act 1979.
- Associated Gas Re-injection Regulations of 1984.
- Federal Environmental Protection Agency (FEPA) Act 1988.
- Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) 1991.
- Environmental Impact Assessment (EIA) Act 1992.
- Gas Flaring (Prohibition and Punishment) Bill 2009.

5.4.4 Monitoring/Enforcement Team

This, in a way will act like the Global Gas Flaring Initiative (GGFRI), which is a private-public partnership that was set up by the World Bank in 2002, to support the petroleum industry, government and development agencies towards their quest for reduction of gas flaring (GGFRI, 2002). There is need for a monitoring team, particularly in Nigeria. This is because from the review carried out by this study on some existing legislation on gas flare reduction in Nigeria, it was deduced that the oil and gas operators in Nigeria fall on the category we termed as the 'rationalist'. The rationalists will not obey the law or act responsibly unless the punishment for such behaviour costs more than the benefit of them acting responsibly (like in the theory of rational crime; based on cost benefit analysis) (Einhorn and Hogarth, 1981). They also consider if they can get away with doing the wrong things; therefore the laws are needed to ensure compliance by this set of people. For such people unless there are laws and sustained enforcement, which can detect non-compliance and punish it, such people and businesses will never do the good things.

The monitoring/enforcement team will always keep the operators on check and also report to the government or appropriate authorities any challenge(s) that the operators encounter. The team will be responsible for making sure that the operators do not flare more than the stipulated volume of gas, and if they do, it is also the duty of the team to report such an offending operator to the appropriate government authority for the appropriate penalty.

Furthermore, this monitoring/enforcement team could also develop means for natural gas utilization for the local communities that are nearer to the gas flaring sites. For example, the flared gas could be converted to liquefied petroleum gas (LGP) to serve, at least the local communities nearby. Therefore, the team facilitates supports and promotes the supposed gas reduction framework. To be more specific, the team will be charged with three major roles/duties:

- ✓ To regulate the dynamics of associated gas.
- ✓ To locally aid the commercialization of natural gas.
- ✓ To regulate the implementation of voluntary standards for gas flaring (which entails "to eliminate or reduce the potential and observed impacts of these activities and to ensure that public safety concerns and environmental impacts are addressed before beginning to flare.)

The liaising exercise and process will comprise representatives from the operators of oil and gas industry, energy firms and representatives from the government. The financial implications of converting flare gas to electricity will be discussed. This will entail a comprehensive cost-effectiveness analysis (CEA), as well as the pros and cons associated with the process. A common ground is accepted and responsibilities will be assigned to various stakeholders involved.

Approval will be obtained from the rightful channel(s) for subsequent implementation of the gas flare management process framework. In Nigeria for example, the Department of Petroleum Resources (DPR) is responsible for petroleum and gas matters (DPR, 2016). However, inasmuch as we are dealing with both gas and electricity, approvals will come from both the DPR and the National Electricity Regulatory Commission (NERC) simultaneously. The NERC is an independent regulatory body with authority for regulation of electricity in Nigeria (NERC, 2016). It is an outcome from the Electric Power Sector Reform Act, 2005. It is responsible for the reviews of electricity tariffs, promotes policies that are efficient, forms and enforces standards in the creation and use of electricity in Nigeria. Furthermore, the electricity generated would be used for three purposes, which include:

- Internal usage: This stipulates that the electricity generated in this process will solely be utilized for the electricity need of the oil and gas operator. This could basically be at their drilling sites; therefore the electricity generated will be used for powering drilling machines, lighting and any other operation that requires energy. In this case, the electricity production will not be huge, and may require lesser capacity of gas turbine (less than 150 MW) depending on the size of the operating size of the site. This definitely results to fewer volume of gas utilization.
- External usage: Electricity produced in this process will be harnessed and added to the national grid system. This will improve the overall energy system in the country and improve the economy also. This is realistic if the amount of electricity produced is greater than the need of the oil and gas operator. Also this will entail the use of a bigger capacity of gas turbine up to 150 MW. And this thereby signifies more gas consumption.
- Internal and external usage: When planned very well, the electricity generated through GTW could both be utilized internally and externally. However, this depends of the amount of electricity produced in such location and availability of the infrastructure like proximity to national grid cables. Surely the importance of electricity can never be over exaggerated in Nigeria particularly, and across the globe in general.

Figure 5.7 is a representation of the framework that guided the study for the development of gas flare management Framework. It gives guidelines and processes for the adoption, prior to implementation of the gas flare management framework developed by this study. It is associated with processes that include the provision and application of policies as well as partnership; effective legislative framework; and also monitoring and enforcement team.

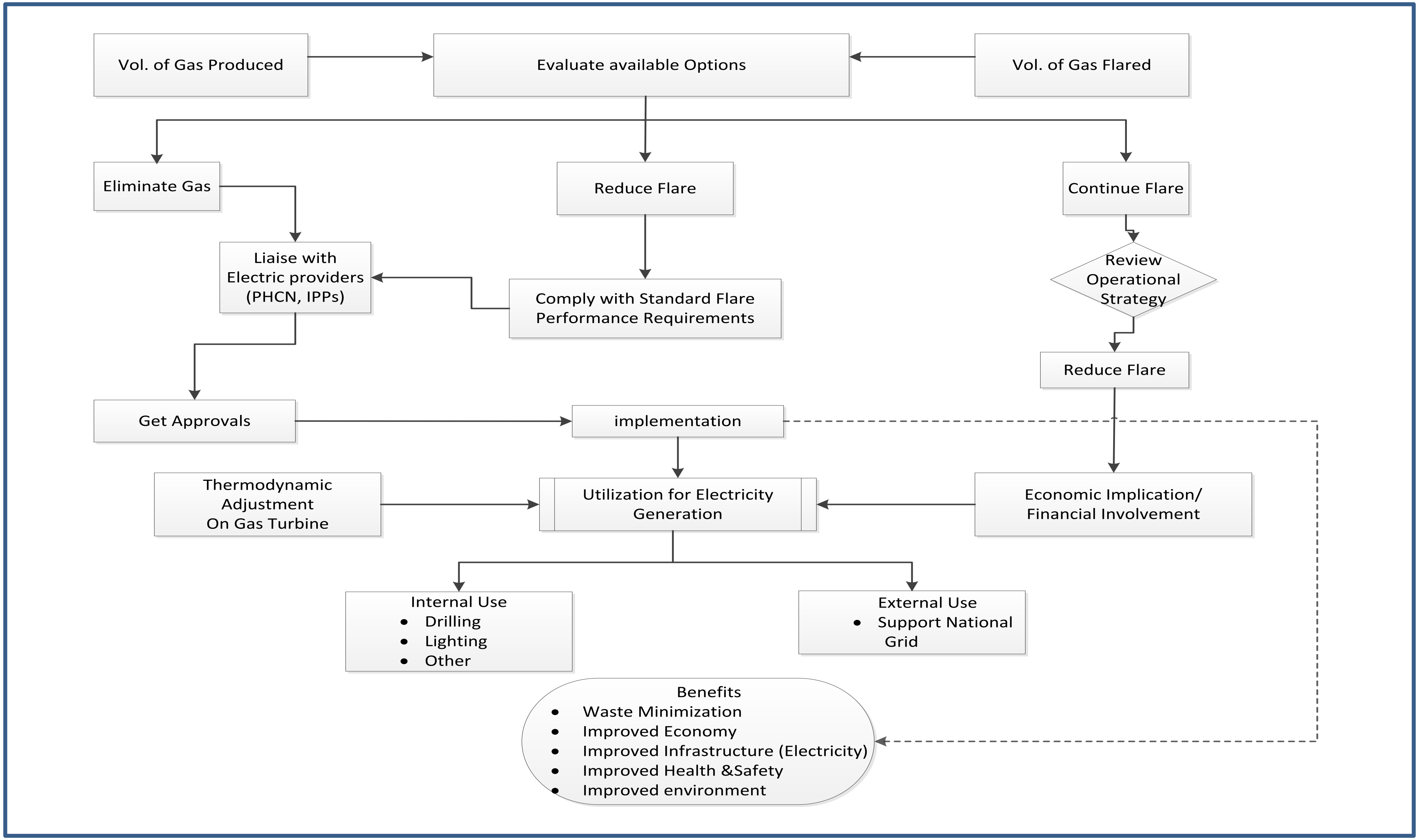

Figure 5. 7: Framework guiding the development of gas flare management framework

As specified in the framework, three gas flare management options are available as evaluation options, namely elimination of flare gas, reduction of flare gas, and continuation of flare. These options have been detailed in Section 5.4.1.1. When a particular option is chosen, the next stage involves interaction between the oil and gas producing organizations and electricity producing organization (for instance PHCN in the case of Nigeria) to create an understanding partnership for investment on electricity generation with flared gas. During this phase, the financial implications as well as other logistics like management of the power plant are discussed. This subsequently leads to application for permission to invest and operate a power plant and potentially successive approval from the government. Immediately this is approved, its implementation takes off. However, during implementation period, the economic/financial involvement is reviewed to re-emphasize and confirm the cost and effect of the use of flared gas for electricity generation; this encompasses the framework of gas turbine, units of turbine, expected expenditure and income. Expectedly, large quantity of electricity will be generated and will be utilised both internally and externally. With regards to external use, the electricity will be transmitted to the national grid and finally transmitted to the end users; while regarding internal use, a small part of the generated electricity will be utilised within site for drilling, lighting the site and also used for any other activity that requires electricity within the site. Finally, this process when put into use will minimize waste, improve economy, encourage cleaner environment, improve health and safety and generally reduce gas flaring.

5.5 DEVELOPMENT OF GAS FLARE MANAGEMENT FRAMEWORK

After analysing the use of GTW for reduction of gas flaring, as well as the economic significance of GTW for managing gas flare, this study subsequently developed and proposed a framework for the management of flare gas as shown in Figure 5.8. In the Section that preceded this, we developed a framework that guided towards successful development of a gas flare management framework. It helped to improve and add value to the management of gas flaring through the use of a power plant. This framework will provide the advantages of using GTW technology to minimise gas flaring, as well as knowledge on the cost and effect. The framework guides and identifies both the input and output in terms of annual gas production, gas flaring, gas usage and electricity generation, as well as financial expenditure and income through GTW technology.

The framework for gas flare reduction is the core output from this research. Therefore to develop it, this research considered various factors in Nigeria, and they included the following:

i. **Volume of gas produced**: this involves the total volume of gas that is produced annually either from associated gas or non-associated gas deposits

ii. Volume of gas utilized: this includes the annual gas utilization after production for various needs, through different technological approaches like Gas Re-injection, Gas to Liquid, Gas to Electricity, Liquefied Natural Gas, Gas to Methanol, as well as through other technologies.

iii. **Volume of gas flared**: during the production of crude oil, most of the associated gas is flared. Therefore this section is responsible for any part of the gas that is produced, but not utilized. In a simple statement, any gas that is not utilized after production is subjected to flaring. This volume is measured per annum.

iv. **Reason for gas flaring**: it is a common knowledge that the act of gas flaring is wasteful and contributes to greenhouse gas in the environment among other negative impacts; yet, it is a common practice in the oil and gas sector. Therefore, in the process of developing the framework for reduction of gas flaring, this research also considered and investigated the reasons for continuous gas flaring in the oil and gas industry, particularly in Nigeria.

v. **Agreement among stakeholders**: this study also explored and showed a potential cooperation between gas production/flaring organizations and the electricity power stations. This directs and highlights the movement of gas from production to utilization, instead of flaring.

vi. **Positive contribution from the government**: government laws and bills play roles in encouraging and supporting the reduction of gas flaring. For instance, promulgation of incentives like of tax holiday or reduction for the oil and gas firms into law could encourage investment towards gas reduction technological tools. Rather than wasteful flaring, money meant for taxation could be channeled towards gas reduction technologies. Also the government could have a joint business venture with these oil and gas firms to support and encourage investment towards gas flare reduction technologies.

vii. The framework also identified the volume of potential gas utilization by the power plant as well as the potential electricity generation from the power plant through specified units of gas turbine. It also stated the expected volume of gas flare reduction as well as the estimated financial implications.

5.5.1 Variables Used In the Framework:

To develop the gas flaring management framework, eight (8) variables were considered and used as guides to show process flow and identify trend of reduction level of gas with the help of the gas flare reduction framework. These variables are explained as follows:

i. **T**: Total gas produced on an annual basis. This is measured in billion cubic meters (BCM).

ii. **Y**: Current utilized gas. Volume of gas that is currently used through different technologies after production.

iii. **X**: Current potential flare gas. Total volume of gas that is meant for flaring immediately after production.

iv. **Q_1**: Prime quantity of gas converted from being flared to being used. It is the initial volume of gas converted from the potential gas flare volume. This volume could be utilized through technologies such as GTW, GTL, LNG, and Re-injection.

v. **Q_2**: Secondary quantity of gas converted from being flared to being used. This volume is converted only as a result of huge volume of gas still remaining for flare after Q_1.

vi. **Q_3:** Residual quantity of flare gas. Volume of gas that ends up being flared after using various technologies to convert the potential gas. It is determined by subtracting both the prime and secondary quantities of gas converted from the potential flare gas.

vii. **Y_f:** Final estimated utilized gas. Total volume of gas that is finally utilized after certain volume of gas has been converted from the initial potential flare gas.

viii. **Z**: Finished product converted from the potential flared gas. With respect to GTW, it the turbine power output (measured in MW), and this is dependent on some variables such as prime quantity of gas converted; secondary quantity of gas converted; units of turbine; thermal efficiency. This is mathematically stated as:

$Z = f(Q_1, Q_2, \text{units of turbine, thermal efficiency})$.

The equations below are useful for the determination of the variables used in the framework for management of gas flaring:

$Y = T – X$ ………………………………………………………………………… (1)

$X = T – Y$ ……………………………………………………………….………... (2)

$Q_1 = X - (Q_2 + Q_3)$…………………………………..…………………...…..….. (3)

$Q_2 = X - (Q_1 + Q_3)$……………………………………………..……..……….… (4)

$Q_3 = X – (Q_1 + Q_2)$ ……………………………. ………………………………… (5)

$Y_f = Y + (Q_1 + Q_2)$ ……………………………………………………….…………… (6)

$Z = f\ (Q_1, Q_2, \text{units of turbine, thermal efficiency})$ ……………………….……... (7)

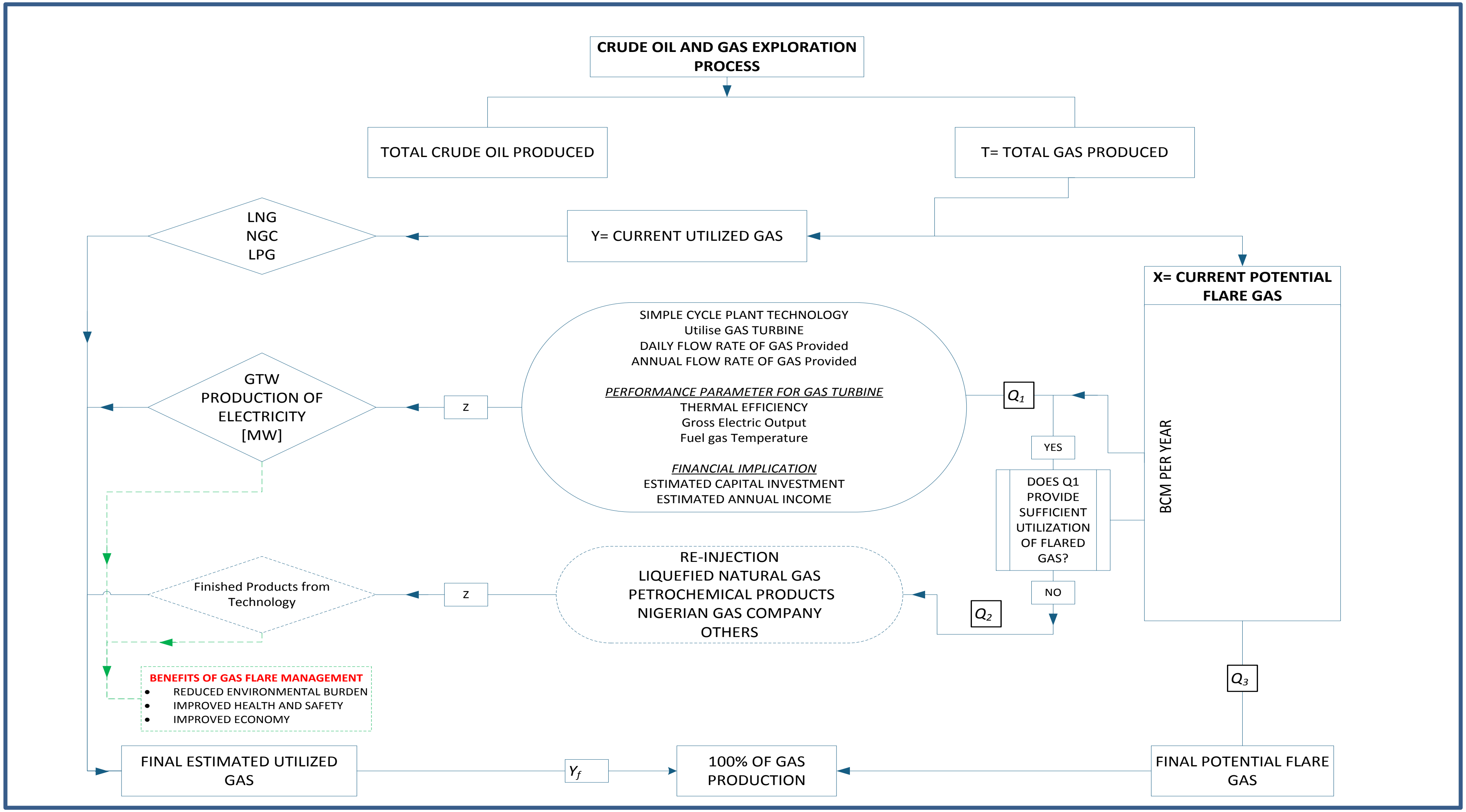

Figure 5. 8: Proposed framework for gas flare management

5.6 FRAMEWORK PRESENTATION IN NIGERIAN CONTEXT

From literatures and case studies carried out in this study as shown in chapters two, three and five, Nigeria has an estimated reserve of natural gas to the tune of 5.3 trillion cubic meters (187 trillion cubic feet) (Ahmed *et al.*, 2012; NLNG, 2011). Furthermore, Giwa et al (2014) states that the annual production of gas in Nigeria is 33.21 BCM; annual gas utilized through LNG, NGC (which further supply gas to specific electric power stations), and some percentage of gas utilized in the form of liquefied petroleum gas is 14.94 BCM; while the annual flared gas (this study mathematically refers it to as Initial Potential Flare Gas [X]) is 18.27 BCM. This gas flare reduction framework, just like the name goes, technically is not expected to totally stop or extinguish gas flaring in Nigeria; rather it is poised to develop viable measures to minimize gas flaring to a low level.

The GTW technology was chosen as the preferable technology for gas reduction in Nigeria, firstly because it is a sustainable means of gas utilization. This is because according to Ahmed, Bello and Idris (2012), electricity is accessible to less than 40% of the Nigerian population; while Iwayemi (2008) highlighted that the electricity production and supply in Nigeria is faced with a huge challenge of inadequacy. Therefore, the use of GTW technology ensures constant utilization of gas by the gas turbines, and could also guarantee improved electricity generation and supply in Nigeria.

This research also took into cognizance the fact that Nigeria is a huge country and potentially one of the leading global economies. However, such potential will rarely be achieved with the epileptic or poor nature of electricity production and supply in Nigeria. Therefore apart from the fact that this framework will minimize waste, improve financial input to the country, reduce environmental hazards, as well as minimize other negative impacts associated with gas flaring, it will also alleviate the electricity scenario of Nigeria, and thereby help to achieve Nigeria's potential as a leading global economy.

5.6.1 Mathematical Framework that Supports Gas Flare Management

The calculations below helped the study to demonstrate and highlight the potential volume of gas flare in Nigeria after the application of GTW technology. They also helped to determine the final estimated volume of utilized gas. Some key variables and figures based on Nigeria as shown below were considered in the framework and were used in the calculations.

KEY FIGURES FROM THE FRAMEWORK:

Total gas production: 33.21 BCM per year

Currently utilized gas: 14.94 BCM per year

Potential flare gas: 18.27 BCM per year

Gas currently used by other technologies: 14.9 BCM

Estimated units of turbines required: 50 Unit of 150 MW capacity each

Expected volume of flared gas prevention: 16.97 BCM per year

Expected amount of electricity generation: 7,500 MW per day (150 MW per turbine)

Estimated capital investment: £1,643,185,000

Expected net profit per year: £1,264,245,500 (£25,284,910 per turbine per year).

5.6.1.1 Determination of the Available Flare Gas after Conversion (q):

This is the final volume of gas flared after conversion from the potential flare gas (X). It is determined by subtracting the volume of gas converted for utilization (Q_1 and Q_2) from the potential flare gas volume. From the calculation, with respect to the Nigerian scenario, the volume of available gas flare is reduced from the initial 18.27 BCM to 1.3 BCM. This can be achieved by the provision and installation of 50 units of gas turbine of 150 MW capacity each.

$Q_3 = X - (Q_1 + Q_2)$ ………………………………………………………………….. (i)

18,270,000,000 – 16,972,500,000 = 1,300,000,000 BCM

Convert to percentage: (1,300,000,000 ÷ 18,270,000,000 x 100) = 7.11% of Current Potential Flare Gas.

5.6.1.2 Determination of the Final Estimated Potential Utilized Gas (Yf):

This is the total volume of gas that could be utilized after production in Nigeria. It is a combination of currently utilized gas and the gas that will be converted from the potential flared gas to fuel gas for the turbines.

$Y_f = Y + (Q_1 + Q_2)$ ………………………………………………………………… (ii)

14,940,000,000 + (16,970,000,000) =31,910,000,000

Convert to percentage: (31,910,000,000 ÷ 33,210,000,000 x 100) = ***96.08 %*** *of total gas produced in Nigeria.*

5.6.1.3 Indicators of Successful GTW Gas Flare Management

Table 6.5 shows the statistics on the use of GTW for the management of gas flaring in Nigeria, with respect to units of gas turbine, volume of gas utilization and electricity production. It highlights various degrees of reduction of volume of gas flare as well as potential amount of electricity generated with stated number of gas turbines. As seen in the Table 5.11, one unit of gas turbine with a capacity of 150 MW can utilise 930,000 m^3 of gas on a daily basis, and this amounts to 339,450,000 m^3 of gas over a period of one year. These volumes of gas generate 150 and 54,750 MW of electricity daily and yearly respectively. These figures double when the number of gas turbine is increased to two. Subsequently, as shown in the table, the amount of electricity that is generated is directly proportional to the volume of gas utilised. It is also worthy to note that the volume of gas utilised is directly proportional to the number of turbines. Therefore, more gas turbines represent less gas flaring (more gas usage) and more electricity generation.

Table 5. 11: Demonstration of Effect of Units of Gas Turbine on Gas Usage and Electricity Production

No. of Gas Turbine (150 MW Capacity)	Vol. of Gas Used Daily (M^3)	Electricity Produced Daily (MW)	Vol. of Gas Used Yearly (M^3)	Electricity Produced Yearly (MW)
1	930,000	150	339,450,000	54,750
2	1,860,000	300	678,900,000	109,500
5	4,650,000	750	1,697,250,000	273,750
10	9,300,000	1,500	3,394,500,000	547,500
15	13,950,000	2,250	5,091,750,000	821,250
20	18,600,000	3000	6,789,000,000	1,095,000
25	23,250,000	3,750	8,486,250,000	1,368,750
30	27,900,000	4,500	10,183,500,000	1,642,500
35	32,550,000	5,250	11,880,750,000	1,916,250
40	37,200,000	6,000	13,578,000,000	2,190,000
45	41,850,000	6,750	15,275,250,000	2,463,750
50	16,972,500,000	7,500	16,972,500,000	2,737,500

For further clarifications, Figures 5.9 and 5.10 have been used to describe the effect of number of gas turbines on gas flaring and electricity production respectively. The graph in Figure 6.9 clearly shows significant and steady increase in gas utilisation with increase in the number of gas turbines.

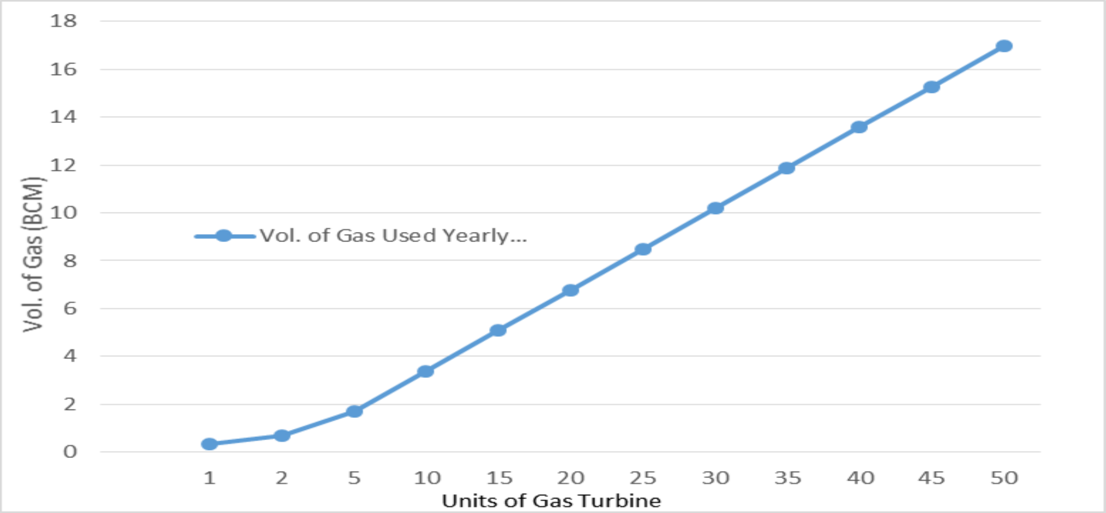

Figure 5. 9: Graph showing units of gas turbine used versus volume of gas reduced

Also with increased units of gas turbine comes significant and steady increase in the amount of electricity produced, as highlighted by the graph in Figure 6.10.

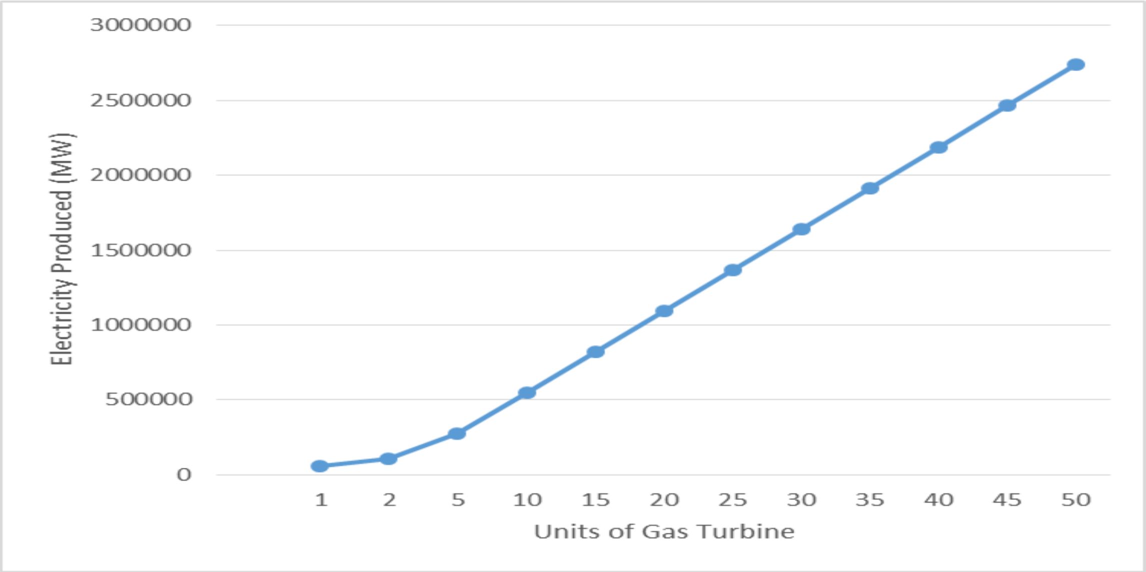

Figure 5. 10: Graph showing units of gas turbine used versus electricity generated

5.7 JUSTIFICATION OF GAS-TO-WIRE (GTW) AS THE TECHNOLOGY TO MANAGE GAS FLARING IN NIGERIA.

The evolution of unconventional gas like shale gas in the U.S., Europe and China has undoubtedly left some implications on the Nigerian gas supply whose major markets have traditionally been the US and Europe. For instance, in 2007, Nigeria exported 97 trillion cubic feet (TCF) of gas to the U.S. representing about 12% of the total imports by US for that year, while in 2011, Nigeria exported to the U.S. just 2.3 BCF of gas (Oyekunle, 2013) and in 2012 Nigeria exported no gas to the U.S. Therefore, it is only rational that the encouragement of local gas consumptions could be the key for gas utilization in Nigeria. Even though the capital investment for GTW could be high, it is also worth noting that its annual profit generated is equally high as this study identified earlier in Section 5.3.3. Moreover, in Nigeria, the infrastructure already exists; therefore, most of the investments will be channeled towards purchase of gas turbines, thereby decreasing the capital cost incurred. Table 5.12 and subsequent paragraphs identified and compared the use of GTW for the management of flare gas in Nigeria, while in Iran research was carried out in an oil refinery.

With regards to Nigeria's current estimation on daily energy generation as well as requirement which are 12,000 MW and 4358 MW respectively. There is need to supplement the energy need in Nigeria; this could be sustainably generated by use of flare gas as fuel for turbines. Therefore, with Nigeria's annual flare rate of 18.27 BCM, and an estimated 50 units of gas turbine of 150 MW each to generate 7,500 MW of electricity, the GTW technology is well suited for the management of flare gas in Nigeria. This is because a turbine utilizes 0.93 million cubic meters (MCM) of gas daily, which signifies 46.5 MCM per day for 50 units of turbine.

Table 5. 12: Insight into Gas Flare Management through GTW in Nigeria and Iran

SUBJECT	NIGERIA VERSUS IRAN
Power Generation	• Nigeria: 7,500 MW Per day • Iran: 2,130 MW Per day
Cost of GTW Investment	• Higher in Nigeria than Iran. This is because more gas turbines are required in Nigeria than in Iran.
Return on Investment	• Annual net profit is a bit greater in Iran than Nigeria
Other Gas Flare Mitigation Methods	• Provision of more units of efficient gas turbines in power stations in both Nigeria and Iran. • Rehabilitation and utilization of existing turbines in the Nigerian power stations. • Application of other gas flare management techniques like Re-injection and LNG in Nigeria.

The potential annual income from GTW investment in Nigeria is greater than Iran. This is mostly due to the fact that more units of gas turbine are required to utilize the flared gas in Nigeria, with the resultant electricity generation. More electricity generated signifies more income from the sales of energy. Although Rahimpour et al (2012) stated that the annual net profit from GTW in Iran is £1.97bn which is higher than the annual net profit of £1.26bn from GTW in Nigeria, it is worth stating that Rahimour et al did not consider subtracting the total capital investment from profit accruing from the first year; whereas this was considered in this study. The electricity tariffs in Nigeria and Iran do not currently have significant effect on the difference in net profit in both scenarios because according to Moshir (2013) the electricity tariff in Iran is £0.07 per kilowatt of electricity and this is also the tariff in Nigeria.

This study identified GTW as the sustainable and practical technology that could be effectively utilized for local consumption of natural gas to avoid environmental damage resulting from gas flare. Nigeria is in need of electricity and GTW will be vital to solve such a problem. GTW technology therefore, will not only minimize the impact of gas flaring, such as the environmental, economic, and health effects; but will also boost the poor energy/electricity supply condition of Nigeria. Currently, one major problem that plagues the power stations in Nigeria is lack of efficient gas turbines. For instance, in one of the study's case companies (CS-2), there is currently just one efficient gas turbine out of twenty units of gas turbine, thereby prompting lower volume of gas utilization and indirectly encouraging gas flaring (Ojijiagwo and Oduoza, 2014). Therefore, this suggests that the availability of gas will not pose a barrier if effective and sufficient units of gas turbine are provided towards GTW technology.

5.8 SUMMARY

This Chapter has established the significance of GTW as a sustainable means to minimize gas flaring. GTW encourages local utilization of gas which also is vital, more especially with global attention on the use of shale gas and lesser attention given to natural gas. The study also identified that the number of efficiently functioning turbines determines the volume of gas used as well as the electricity generated in the Electric Company. As specifically identified in this study, increased number of gas turbines means improved electricity generation, and leads to gas flare minimization. Although this involves huge financial capital investment, its income is an encouraging factor towards the adoption of this technology. This study developed a framework which acted as a platform for the development of the research's proposed gas flare management framework. In the Nigerian context, the framework demonstrated how Nigeria as a gas flaring country could convert about 16.93 BCM of currently flared gas to electricity generation on an annual basis. This process and technology does not only minimise environment, health and safety hazards, it also proves to be economically viable and profitable. A capital investment of £1.64bn is needed and it returns a net profit of £1.26bn/year, and has a rate of return of investment of 16.3%.

CHAPTER SIX: RESEARCH AND FRAMEWORK VALIDATIONS

6.1 INTRODUCTION

This chapter discusses the validation of the study carried out here, which develops the framework for gas flare management with additional benefits of energy generation. Research validation is vital because it reveals the potential objectivity and reliability of the research. Furthermore, it provides a solid background along which the research findings could be generalised. The framework for gas flare management was designed and proposed based on the research findings and recommendations to assist in reduction of flared gas. It encourages utilization of gas that would have been flared, while improving the environment, economy and health and safety. There is need therefore to test the validity of the framework before it can be widely disseminated and put into practice. The aim of the validation process is to determine whether the research findings and recommendations used for developing the framework are sound and also, to establish whether these findings and recommendations are reliable.

6.2 CONCEPT OF VALIDATION

According to Kennedy *et al.* (2005), validation of a framework is vital because it attributes confidence and makes a process or a framework to become reliable. Therefore, validation is a key component of the framework development process that proves its potential for wider application. Winter (2000) stated that validation is not a single, fixed or universal concept, but a dependent idea, inevitably grounded in the process and intentions of particular research projects and methodologies. The following section has been divided into two broad subsections – research validation and framework validation.

6.2.1 Research Validation

This research was carried out through a case study approach; therefore this validation process is a reflection of the findings from the case study. Meredith (1998) reported that the use of case studies in research has advantages such as relevance, understanding and explanatory depth; however, Aldag and Sterans (1998) have also shown in their research that there is a common perception that case study research exhibits the tendency for construct error, poor validation and questionable generalization. The high level of subjectivity involved in the analysis of case study research or qualitative data calls for the need for verification of results or findings (Merriam, 2014; Silverman, 2015). Burbard *et al.* (2008) suggest that, different researchers may interpret the same qualitative data differently and as a result qualitative accounts cannot be held straightforwardly for representation. These concerns call for the need to validate research findings or claims through a rigorous analytical approach which also has the tendency to reduce bias (Mays and Pope, 1995; Barbour, 2001; Silverman, 2015).

Simons (2009) suggests the validation of findings from a qualitative research takes two main forms: triangulation and respondent validation. Triangulation deals with seeing things from different angles to help determine the validity of claims made based on the data, whereas respondent validation deals with the process of interpretation of findings from a research. Suggestions by both Yin (2013) and Simons (2009) were taken into consideration to ensure the validity of the case study results. This research adopted a number of measures as advised by Yin (2013) and Merriam (2014) such as construct validity, internal validity and external validity.

6.2.1.1 Construct Validity

Certain measures have demonstrated to contribute towards construct validity in qualitative research and these include triangulation (establishing a chain of evidence), and participant validation (Yin, 2013; Burnard *et al.* 2008).

6.2.1.1.1 Triangulation of case study findings

This comes up as a confirmation of validity of responses (Stake, 1995). According to Yin (2013), for multiple case studies, this can be achieved using multiple sources of data. Triangulation deals with the means of cross-checking significance of issues or the testing out of arguments and perspectives from different angles to generate and strengthen evidence in support of key claims (Simons, 2009). The use of triangulation is deemed very important in case study research so as to create a holistic view of the subject under study, by examining and analysing information from different sources (Ghauri and Grønhaug, 2002). According to Denzin (1989) and Flick (1992), triangulation helps to clarify meanings by identifying different ways the issue under study is seen, by reducing the likelihood of misinterpretations. There are four means of achieving triangulation: data source triangulation, where different sources of data are collected on the same phenomenon; investigator triangulation, where different investigators examine the same phenomenon; theory triangulation, where investigators with different viewpoints interpret the results; and methodological triangulation, where one approach is followed by another to increase confidence in interpretation.

The significance of methodological and data source triangulation is to look at things from different perspectives by using different means of data collection or different data sources to get a broader view of things (Barbour, 2001). Therefore, in this study, methodological triangulation was achieved by acquiring data through three different methods such as interviews, documentary analysis and observations during visits to the three case companies used as case studies in this study. To ensure multiple viewpoints in the data set, data source triangulation was also achieved by interviewing personnel from different positions within the case companies. The research interviewed top personnel such as production manager, operations supervisor, health and safety manager, operations and maintenance manager and, technical supervisor on similar issues relating to gas production, utilisation and flaring.

6.2.1.1.2 Participant/Respondent Validation

According to Ashworth (1993), there is a question mark on the validity of qualitative research particularly with regards to avoidance of prejudice in results. This is where the need for participant validation comes to bear as it seeks to ensure that the views of participants are not misinterpreted. To be able to test the appropriateness of an account of the personal meaning of a situation, the best approach according to Ashworth (1993) is to ask the research participants themselves. Therefore, participant validation involves returning to respondents and asking them to carefully read interview transcripts or results of initial data analyses to validate or refute the researcher's interpretation of the data (Burnard *et al.* 2008; Yin 2013). Though respondent validation is regarded as an integral aspect of qualitative research, a number of researchers question its appropriateness due to the different concerns of both researchers and respondents. As reported in Barbour (2001), whereas researchers seek to an overview, respondents may have individual concerns and this can result in discrepancies. For this reason, Atkinson (1997) warns against the dangers of researchers incorporating the sentiments of respondents at the expense of their own interpretations (Barbour, 2001).

Participant validation for this research involved contacting relevant participants to reconfirm certain information that were got during the case studies that looked unclear, just to ensure their views have not been misrepresented. This was mainly applied in case studies 2 and 3, which are two different electricity generation companies.

6.2.1.2 Internal Validity

Due to the high level of subjectivity involved in qualitative research or case studies, Yin (2013) suggested that internal validity is required to ensure the right inferences are made from the data received. For internal validity to be achieved, there is the need to do pattern matching, explanation building and time service analysis (Yin, 2013).This was achieved in this research through meetings with research participants (top ranking personnel of the case companies) to discuss the demands of the research and ensure there was a clear understanding of the research. The interview guides were emailed to the research participants in advance, to guarantee they understood the questions and had the chance to seek clarification in advance where questions were not very clear. This process also helped in modification of interview guides where required. Another method whereby this study achieved internal validity is through participant validation (see section 7.1.1.1.2).

6.2.1.3 External validity

External validity determines the limits to which the findings of the research could be generalised (Yin, 2013). Two main ways of achieving external validity are the use of theory for single case studies whereas replication logic could be used for multiple case studies. To ensure external validity in this research, a multiple fixed case study approach using three companies was adopted. This ensured that the research was replicated three times regarding investigations on gas flare reduction management. By this approach, all cases were compared with each other through a cross cases analysis. In addition, there are academic publications developed during the research process, which were all subjected to peer review to ensure valid arguments were made. The abstracts of these academic papers have been affixed as Appendices G, H and I.

6.2.1.4 Reliability

In case study research, reliability is needed to ensure the same findings can be achieved through a repeat of the research (Yin, 2013; Merriam, 2014; Silverman, 2015). To achieve reliability, it is essential to certify the research proceeds through a transparent process, giving enough detail of the strategy as well as data analysis process (Silverman, 2011; Merriam, 2014). Subsequently, Yin (2013) suggests the importance of a case study protocol and a case study database. To ensure reliability in this research, full details of the research from the design of the case studies, through the selection of cases to the collection of data are presented in chapter four. Also shown in chapter four is a detailed data analysis process. A case study protocol was developed for this research which included interview guides and data collection plan. The data collection plan contained a detailed breakdown of information sources: interview guides, project data sheets, observation sheets and summary sheets; a brief description of the kind of information sought from each source, the kind of people or informants required for data. Two different interview guides were prepared: interview guide for oil and gas producing company (case study company 1) and interview guide for electricity producing company(case study companies 2 and 3) (see Appendix A and B).

To ensure a consistent and systematic data collection process, the same case study protocol was employed across all 3 case studies. To ensure systematic and rigorous analyses of the data, there is the need to ensure all data collected are thoroughly analysed. Burbard *et al.* (2008) suggested that this should include the search and identification of relevant deviant or contrary cases that may not agree with the main findings. A full detail of the data analysis process has been given in chapter 4 of this thesis (section 4.5), which shows how systematic the process was carried out. Also, this helped to guarantee transparency in the process.

6.2.2 Validation of the Proposed Framework for Gas Flare Management

As an output from this research a framework for gas flare management is developed to help manage flared gas through GTW technology (See section 6.5). Therefore, this section presents information on the validation of the framework to determine its usefulness and adequacy in helping to solve the problem of gas flaring.

Framework or model validity is appropriate, especially in the light of the purposes of investigation (Frees, 1996). Egbu (2007) describes the validation of a model or framework as the process of assessing the ability of the framework or model to do what it sets out to achieve. According to Ankrah (2007), validation process weighs the performance level of a model as well as a framework. For the reasons given above, the validation process in this study was done to establish that the framework for gas flare management as developed and proposed in Chapter 5 is evaluated to establish the extent of its effectiveness in the oil and gas sector with respect to utilization and reduction of flared gas.

The validation was carried out using face validity. According to Leedy and Omrod (2001), face validity is an independent verdict of no statistical nature that seeks the opinion of non-researchers regarding the validity of a particular study. Lucko (2010) stated that the strongest route to establishing face validity is through the involvement and collaboration of experts from the field of study through active collaboration or at advisory capacity. To achieve face validity in this research, professionals in the oil and gas industry as well as from the electricity producing industry participated actively during the data collection period. After data analysis, these professionals were also consulted for the validation of the framework, which is the output from the research.

As stated by Lucko (2010), the strongest way to establish face validity is the involvement of domain experts, also known as subject matter experts, before, during, after, or throughout the research. Such participation can range from an advisory capacity to active collaboration. Obviously, the earlier and the more such input is sought, the stronger it can contribute to face validity. In this research, experts from three organisations in both oil and gas sector and electricity sector were involved starting from the data collection phase, and were also consulted for validation of the framework developed. This process gradually provides vital involvement as it takes a more active role in initiating, supporting, and implementing the research that seeks to provide solutions to flared gas management.

Validity, and in this instance the framework validity is concerned with whether the developed framework for flared gas management is believable and true as well as whether it is capable of achieving what it sets out to achieve as stated from the inception. Therefore, in this regard, Burns (2003) highlights that validity is a vital benchmark for weighing the quality and acceptability of a framework or model. Putting further credibility to validity, Zohrabi (2013) stated that validity is a matter of trustworthiness, dependability and utility that the evaluators and stakeholders place into it. Therefore, it is within reach to subject model/framework validity to professionals or experts who are part of the framework development at some point, but with no direct influence (Fraenkel and Wallen, 2003).

6.2.2.1 The Face Validity

In applying face validity, this study carried out structured interviews on selected professionals from the three case companies used for this research. A review of these professionals has been shown in Table 6.1. Two participants from each case company, making a total of 6 participants were carefully chosen based on their knowledge and experience on gas flaring and electricity generation in Nigeria. During data collection phase/process, these principal officers/experts were notified about the validation process and their consents for participation were successfully acquired, pending actual time for the interview.

Table 6. 1: Background of participants for validation

Participant	Company	Position	Experience
1	CS-1	Operations Supervisor	15 years
2	CS-1	Production Manager	10 years
3	CS-2	Field Operator	8 years
4	CS-2	Operations supervisor	7 years
5	CS-3	Power Plant Operator	12 years
6	CS-3	Electrical Maintenance Repairer	14 years

After development of the framework, these key officers were all contacted once more and their willingness to participate in the validation process was obtained. Subsequently, copies of the framework for gas flare management developed by the study were forwarded to them through email. Also, the themes of the interview were forwarded to them to give them idea of the focus of the validation. Due to distance, time and other logistics, these interviews were carried out over the telephone. However, every effort was made to ensure that the telephone interview gave the best outcome for the face validity. An audio recording and note taking during the sessions were applied and they proved helpful.

6.2.2.2 Purpose for Framework Validation

The essence of the validation of the gas flare management framework is summarised in the list below:

a. Assess the adequacy of the framework in leading to gas glare management in Nigeria
b. Determine the clarity and feasibility of using the framework
c. Confirm from the participants if the estimated costs and benefits of the framework are realistic
d. Identify how achievable/realistic the expected profit from using GTW technology will be in Nigeria.
e. Establish potential for framework use by other researchers operating in different oil and gas environments.

6.2.2.3 Questions for Validation of Proposed Gas Flare Management Framework

The questions were generally categorised into six main sections which captured all the areas of the framework that need to be validated. These questions are clearly shown as follows:

1. Does the framework provide a structured, well-informed and holistic approach for gas flare management using GTW technology?
2. Can the proposed framework for gas flare management in Nigeria be capable of minimizing the problem of flared gas?
3. How feasible is the recommendation to use 50 units of turbine as proposed by the framework, with regards to cost and logistics?
4. Does the overall estimated cost for gas flare management using GTW technology as stated in the framework appear realistic?
5. How realistic is the expected financial income from GTW technology as an alternative to gas flaring?
6. The framework suggests that using GTW can help produce 7,500 MW of electricity from flared gas in Nigeria. Do you think this is achievable?

6.2.2.4 Validation Process

As part of the validation, interviews were conducted with the participants after they had all been sent copies of the proposed framework together with a short write up of the framework and its intended goals. The participants were sent a list of open ended questions to be used as the basis for validating the framework. The open ended questionnaire (interview guide) had six questions which relate to the usefulness, feasibility and clarity of the propositions of the framework.

After the participants had gone through the framework, the write up and the questions that accompanied them, a date was fixed for a time convenient for the participants where a phone interview was conducted to validate the framework. During this time, participants were given the chance to ask questions or for clarity before the process began. After participants were ready to proceed with the validation process, the process finally kicked off. The interviews lasted for an average of 20 minutes for each interviewee, and were given the chance to freely express themselves based on the questions asked. The interviews were then transcribed and analysed based on the four main themes determined by the six questions used as the basis for the validation.

6.2.2.5 Feedback from the Validation

The validation of the framework was conducted unto four main themes and the results have been discussed based on the following headings.

6.2.2.5.1 Adequacy of the Framework in Leading to Effective Gas Flaring Management

The results of the validation indicated that the framework presents an adequate effort to manage flared gas in Nigeria. All respondents were of the view that the proposals of the framework will be an effective way of managing the gas flaring situation in Nigeria. Respondents showed a general agreement for the use of GTW as the most effective means of managing the gas flaring situation in Nigeria, especially looking at the current situation of inefficient power supply to homes in Nigeria. The proposed framework was therefore seen as a contribution to solution of electricity generation and supply in Nigeria. Typical comments to suggest this were from the operations manager, as well as production manager in case study company 1. The Operations Manager suggested that "*the framework can help in so many ways if there is the resource to carry out what it proposes. I think being in charge of operations and being aware of the amount* *of gas we flare constantly on a daily basis, this framework presents a simple and adequate attempt to manage the problem".* Subsequently, he stated that *"I believe this method of gas flare management will prove very relevant because it will be sustainable due to the fact that electric energy is perpetually needed and that means we don't need to flare gas any more, rather we can channel to the electricity producing companies, who need the gas as steady source of fuel for electricity production.*

The production manager had this to say "*We have been looking into Gas to Wire (GTW) as a means for us to reduce the wastage levels from our station. We do some level of GTW but never thought of it in terms of use at such a large scale. I think the best way forward will be this framework. I mean this approach to the situation will be the best means to generate a lot more electricity.* The general agreement on the adequacy of the framework is based on the scale of benefits expected from investing in GTW on a large scale.

The power plant operator and operations supervisor from the electricity companies also concurred that the framework can be effective towards gas flare reduction. According to the operations supervisor, the framework has demonstrated that the process can help towards gas delivery to the power stations. "*As far as the gas is delivered to the power stations, utilisation will be guaranteed, and this will reduce gas flaring*".

6.2.2.5.2 Usefulness of the Framework

In terms of usefulness, all six participants involved in the validation process agreed to the usefulness of the framework. As stated by the operations supervisor of case study company 2, "*I find this framework to be useful as I can see what you are trying to achieve here. I see a future for something like this being used for management of flared gas."* Other participants made comments suggesting that the framework presents a useful way of looking at the gas flaring situation. The production manager in case study company 1 made this statement concerning the usefulness of the framework "*I think it makes a lot more sense to look at the problem from the broader picture, and this is what this framework has just done. This is what makes your framework useful, looking at it in terms of total flared gas makes it very useful and shows the possibility of doing something big with the gas".* The power plant operator from case study company 3 stated that "this *framework has just shown that it is very possible to improve significantly the amount of electricity produced from this station and in Nigeria in general. If* *only we could provide effective gas turbines in our power station, we could achieve two vital results – reduce gas flare and improve electricity generation".* Other participants at various capacities also suggested that the framework is useful due to the level at which it considers the gas flaring issue, and the projected amount of electricity the combined flared gas could generate.

Consequently, the electrical maintenance repairer from case study company 3 suggested that the framework can form the basis for planning for a nationwide initiative for gas flare management and a step towards increasing the amount of electric power available to the country. Also the field operator from case study company 2 stated that "*The important thing about this framework from my point of view is that it has combined all the potential flared gas and shows the potential amount of electricity to be generated. This to me gives the big picture and makes the framework very useful for planning purposes"* The usefulness of the framework was acknowledged by all participants in the validation process.

6.2.2.5.3 Practicability of the Framework

This section discusses how feasible the recommendations of the framework are especially regarding the level of investment required to convert the gas currently flared into energy or electricity. In terms of feasibility, although there was a general agreement as to the feasibility of the recommendations, there were some uncertainties as to how this will work in practice.

Though the recommendations were deemed very important by the participants in the validation process, the general opinion was that the framework could be viewed as a global solution and not a single company based; and as such it will require efforts from a nationwide point of view. The operation manager from case study company 1 raised a question as part of the feasibility of the recommendations "*I want to know, how you get all the flared gas together considering the fact that gas flare site in Nigeria are scattered around?."* The production manager from case study company 1 showed his interest on the framework when he stated as follows "*I like the framework and the recommendations, but I don't quite see how you get all the flared gas to create that power station with 50 turbines".* Subsequently, he asked a similar question "*How cost effective will it be to collect all potential flare gass in one place?* These questions and many more from the participants suggested that though the framework is useful (according to the participants), there were issues with the feasibility of the recommendations especially gathering the gas into a central unit to make use of the GTW as an option for managing it.

In terms of the number of turbines required to be set up for producing electricity from the flared gas, there was a general agreement on the feasibility of having the turbines. It was however explained to the participants that there are technologies for collecting all the flared gas from various sites into a pool.

6.2.2.5.4 Robustness of the Propositions of the Framework

The framework was tested to validate it for robustness. All participants for the validation process found the propositions in the framework reasonable and found the cost implications and saving sensible. The framework was identified to be a good attempt to make good use of the flared gas in the oil production states and cities. The comments of the operations supervisor for case study company 2 suggested that if the framework is put into practice, it will make a meaningful contribution to the power crisis in Nigeria due to novelty and robustness. In his words *"I think this framework makes a lot of sense and can have a positive impact on our power crisis. Gas is constantly flared, and looking at what you are proposing here, we stand a better chance of making good use of it if we bring all flared gas together."* The operations manager from case study company 1 made a similar statement: "*For me, I think this framework shows a whole new picture of the current issue. Because gas is flared from different sites, you do not see the huge financial saving we can make from it. But as your framework has shown, if we can get it all together we stand a better chance of producing more electricity which will add to the national grid and perhaps improve the current situation as power supply is hardly stable in this country; this also comes along with huge financial income".*

Other responses from the interviews also suggested that the framework is coherent especially on the amount of electricity likely to be produced when the flared gas is collected and utilized for GTW. According to the power plant operator from case study company 3, *"to be honest, putting this framework to use will save the electricity sector in this country a lot of problems particularly low electricity production, and this will even help the sector to reduce its financial dependence on the federal government".* The main concern of the participants, however, is how the gas could be entirely collected.

The validation process helped to prove that the framework developed from this research for managing flared gas was: adequate; useful; reasonable; and feasible and presents an opportunity to convert flared gas from a burden on the environment to a source of electricity on a national scale.

6.3 MODIFIED FRAMEWORK FOR FLARE GAS MANAGEMENT

The main concern shown by the participants during framework validation was how the gas would be gathered prior to utilisation. To deal with that challenge, the study demonstrated that the multiple gathering system approach will be applied as explained in chapter six (see section 6.22). Therefore, the original framework has been modified and the multiple gas gathering process has been included. Also the Nigerian scenario has been integrated into the framework, whereby real figures and financial costs have been calculated as integral components.

6.4 PRESENTATION OF MODIFIED FRAMEWORK

Figure 6.1 which is a modified version of the proposed framework for gas flare management takes into consideration the current volume of gas produced, utilized and flared in Nigeria, as well as current amount of electricity produced and estimated amount of electricity needed in Nigeria.

It is a direct modification from the generic framework for gas flare management, as earlier designed and proposed in chapter 5 (Figure 5.8). It takes into consideration the current volume of gas produced, utilized and flared in Nigeria. It shows a flowchart proposing significant reduction of gas flare in Nigeria from 18.27 BCM to 1.3 BCM per year. This reduction is as a result of flared gas being used by gas turbines for generation of electricity. This signifies 92.9% of annual flare gas utilization through GTW. As shown in the framework, a total of 33.21 BCM of gas is produced annually in Nigeria during crude oil and gas exploration. Out of that, 14.94 BCM is currently utilized through liquefied natural gas (LNG), liquefied petroleum gas (LPG), gas to liquid (GTL) and a relatively small quantity is utilized for electricity production through the Nigeria Gas Company (NGC). The remainder, which is 18.27 BCM, is wasted through flaring.

To significantly minimise the amount of flared gas, Q_1 (prime quantity of gas) is converted to GTW. This action involves the gathering of gas to centralised reservoirs through the proposed multiple gas gathering system. Gas is gathered through pipelines to a prime pool, and is further dispatched to electric power stations to power 50 units of gas turbine of 150 MW capacity each, with thermal efficiency of 36%. A single gas turbine of 150 MW capacity utilises 0.93 million cubic meters (MCM) per day, which signifies 46.5 MCM per day for 50 units of gas turbine. The financial inference at this stage of the framework includes an estimated capital investment of £1.64bn, with a larger portion going towards the purchase of gas turbines; and an annual estimated income of £1.26bn. The annual estimated income comes as a result of sales of 7500 MW of electricity generated from 50 units of gas turbine.

However, the proposed framework for gas flare management made provision for other gas flare management technologies apart from GTW. Even though GTW is the primary technology, it made provision for other technologies such as LNG, LPG, GTL, reinjection to act as support or as secondary means of gas flare management to further prevent excessive gas flaring. Therefore, whatever volume of gas that could not be converted and used by the gas turbines for electricity generation (whatever volume of gas that remains after the application of GTW), could further be utilized through one or more of the earlier stated technologies for the production of liquefied gas or domestic cooking gas. This is effective when GTW technology is not capable of utilising all the potential flared gas; therefore, Q_2 (secondary quantity of gas) is converted to a chosen technology like LNG, re-injection or GTL.

The adoption and accurate application of this framework will significantly reduce gas flaring by 92.89% in Nigeria. It also has other benefits apart from gas flare reduction, such as reduced environmental impact, improved environment, and improved health and safety. Therefore, this framework could also be applied in oil and gas processing environments that are similar to Nigeria, where gas is flared

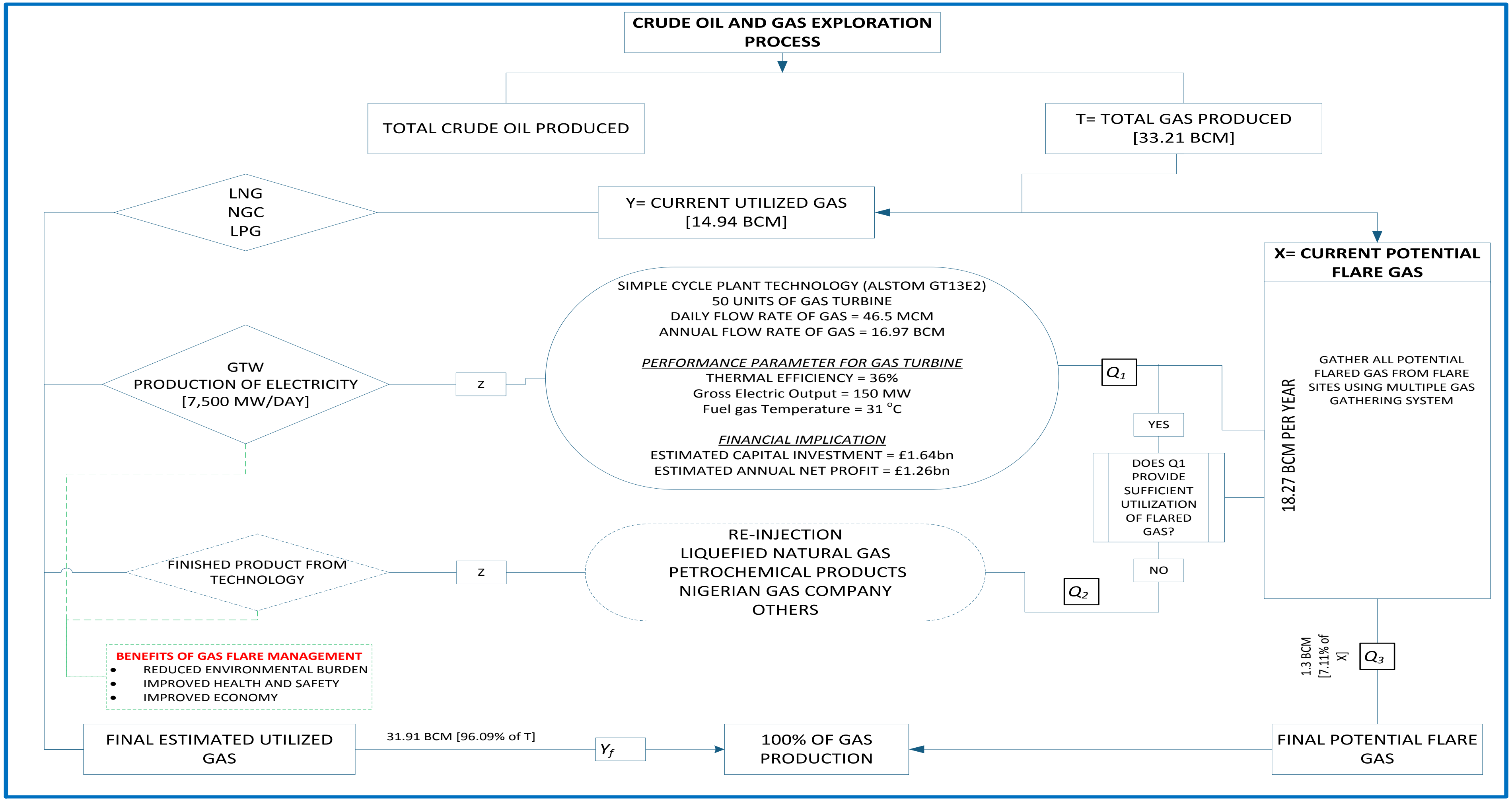

Figure 6. 1: Modified Framework for Flared Gas Management

Where T = Total gas produced on an annual basis in Nigeria

Y = Current utilized gas

X = Current potential flare gas

Q_1 = Primary quantity of gas converted from being flared to being used

Q_2 = Secondary quantity of gas converted from being flared to being used

Q_3 = Residual quantity of flare gas

$Y_{f:}$ = Final estimated utilized gas

Z = Finished product converted from the potential flared gas. This is mathematically stated as: Z = $f(Q_1, Q_2$, units of turbine, thermal efficiency).

6.5 SUMMARY

The importance of validating both the research and the framework for gas flare management has been demonstrated in this chapter. As a qualitative research, which faces the challenge of questionable generalization, this chapter has shown how validity was achieved in this research. The study ensured construct validity, which involves the use of triangulation to cross-check the case study findings; participant validation, where the views of the participants, other than the researcher were consulted; internal validity, which requires that the right inferences are made from the data received; and external validity, where the study used three case studies for the purpose of replication of findings, and also the academic publications from the study which underwent peer review.

Also in this chapter, the framework for gas flare management, which was developed in the previous chapter, was validated through face validity. This was based on four major themes such as reasonableness of the propositions of the framework, feasibility of recommendations of the framework, usefulness of the framework and, adequacy of the framework in leading to effective gas flaring management. The participants who included two top ranking personnel each from the three case studies used in this study all responded on the affirmative. However, on issues bothering the feasibility of the framework, the participants raised concerns on means of gas gathering. The study suggested the multiple gas gathering system, which involves gathering of gas from more than one gas flare source to a prime base with the help of pipelines.

Subsequently, the framework was modified to incorporate a gas gathering system and demonstrating the Nigerian scenario as advised by the experts from oil and gas, and electricity producing sectors.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

This research is designed to investigate gas-flaring practice in Nigeria and to develop a framework to help managed the flared gas by converting it to electricity through gas to wire (GTW) technology. This chapter concludes the research by summarizing the entire research through: reviewing the level at which the aim and objectives of this research have been achieved; presenting the main conclusions, contributions and limitation of this research. The chapter also presents potential industrial applications of the findings of this research with emphasis on the use of the framework for gas flare management as a means to collect and convert flared gas into electricity and recommendations for future research.

7.2 ACHIEVEMENT OF THE RESEARCH AIM AND OBJECTIVES

The aim of this research is to develop a framework, whose adoption would lead to further utilization of flare gas by conversion to electricity through GTW technology. To be able to achieve this, 5 objectives were outlined in chapter 1 of this thesis. The various means of achieving the objectives of the research are presented in table 7.1 below.

Table 7. 1: Achievement of research objectives

Research Aim	Research Objective	Method of achievement	Chapter Presented
To develop a framework that would enable management of gas flaring in the oil and gas environment by generating energy from it, as well as minimizing environmental impacts arising from it.	1. To concisely review literature on gas flaring and some gas flare reduction technologies	Review of precise literature on gas production, utilization and flaring in Nigeria.	Chapter Two
	2. To evaluate gas production, utilization and flaring activities in Nigeria	Extensive interviews, documentary analysis, and site observations	Chapter Four
	3. To review and evaluate the technological implications of GTW.	Review of precise literature on gas turbine thermodynamics and operations.	Chapters Two
	4. To evaluate the financial analysis of GTW technology	Extensive assessment of the economics of power generation with flared gas. Extensive documentary analysis	Chapters Four and Five
	5. To develop and validate a framework for gas flare management.	Extensive interviews, documentary analysis, and site observations using three case study companies. Analysed all data received using QSR NVivo 10 data analysis software.	Chapters Four, Five and Six

7.2.1 Objective 1

The first objective of this study was to review the literature on the issue of gas flaring and the technologies available for reduction the amount of gas flared. This was achieved in chapter 2 of this thesis. The review of literature covered literature in developed as well as developing countries and served as a means to have an updated view of the current thinking in the subject area. This ultimately influenced the choice of gas flaring management technology proposed for by the research.

7.2.2 Objective 2

The second objective focused on study of gas production, utilization and flaring activities in the study area, Nigeria. This objective was achieved in chapter 4 of this thesis and involved the use of extensive interviews and documentary analysis from three case companies within the oil rich region of Nigeria. An oil and gas producing company as well as two electricity-producing companies formed the basis for data collection through a qualitative research approach. This objective focused also on the flaring activities of these companies as well as current strategies they adopt in meeting reducing the levels of gas flared. The causes of flaring as well as potentials for reducing or managing the flared gas through GTW were ascertained as part of this objective.

7.2.3 Objective 3

The third objective of this research is to evaluate the technological implications involved in sustainably converting flare gas to electricity. This study assessed the sustainability of converting gas to GTW in Nigeria. This was achieved by assessing the technological demands and implications of GTW and its suitability for the Nigerian context as a gas flare management options in Nigeria. This objective was is achieved in chapter two through review of literature on gas turbine thermodynamics and operations. The achievement of this objective was also made possible with the knowledge on the levels of flared gas in Nigeria as well as current utilization options adopted by oil and gas production firms in the country.

7.2.4 Objective 4

Objective four of this research is to evaluate the financial implications involved in sustainably converting flare gas to electricity. This is achieved by assessing the financial implications of using GTW as a gas flare management options in Nigeria. The results showed GTW could be a cost effective and viable gas flare management option in Nigeria. The ALSTOM GT13E2, which is a simple gas turbine with a capacity of 150 MW of electricity per day, is used for the assessment with 50 units of gas turbine. These 50 units of gas turbines consume 46.5 million cubic meters of gas per day and produce 7500 MW of electricity per day. The study identified that this project could be achieved with a financial investment of one billion, six hundred and forty three million, one hundred and eighty five thousand pounds (£1,643,185,000). In addition, the investment brings about an estimated annual net profit of one billion, two hundred and sixty four million, two hundred and sixty four thousand, five hundred pounds (£1,264,245,500). Therefore, from these findings, this study suggests this is a good technological approach for gas flare reduction in Nigeria. This objective is achieved in chapters four and five.

7.2.5 Objective5

The fifth objective is the product or outcome of the research; it is to develop and validate a framework for gas flare management. This was achieved by drawing inferences from the results of the research. The results informed the researcher on the volumes of gas production, utilization and flaring in Nigeria. The framework developed, highlights the current scenario regarding gas production, utilization, and flaring; and further addresses a viable mode of gas utilization as well as potential outcome in terms of electricity generation. Other benefits associated with minimized volume of gas flaring such as reduced environmental degradation, improved health and safety, and improved economy were also given consideration. The framework was developed based on the data collected from the case study companies. The validation of the framework was done through further interviews with six professionals who assessed the adequacy and completeness, clarity and easy usage, reliability and feasibility of the framework. This objective was achieved in chapters four, five and six of this thesis.

7.3 RESEARCH CONTRIBUTIONS

The contributions of this research are presented based on three main areas as shown below: theoretical contributions; methodological contributions; and practical contributions.

7.3.1 Contributions to Knowledge

Fundamentally, the issue of gas flaring is not under-emphasized because of researches that have been carried out and still on going by researchers, however, what is lacking is an empirically grounded process that will help the operators of the oil and gas industry to facilitate significant reduction of flare gas particularly in developing countries like Nigeria.

Therefore, this research explains the challenges surrounding gas flaring, particularly in Nigerian context. Because this research is set out to provide sustainable management procedure for gas flaring, its findings also target at providing an understanding of issues linked with gas flaring reduction.

The contributions from this research are specifically stated to include the following:

1. Established that GTW technology could significantly reduce the annual volume of flared gas in Nigeria from 18.27 BCM to 1.3 BCM.

2. Presented an economic evaluation, which demonstrates that GTW technique of gas management using gas turbines in Nigeria is sustainable and profitable. It was established that this level of investment requires 50 units of gas turbines of 150 MW capacity each, and will comprise a startup capital investment of £1.6bn. In addition, this huge investment will potentially yield a yearly net profit of £1.26bn.

3. Develop a framework for gas flare reduction. This provides a strategy for the reduction and management of gas flaring in Nigeria, and it systematically demonstrates that the volume of flared gas in Nigeria could be significantly reduced by 92.89% through GTW technique. This framework could also be applied to gas flaring countries with similar situation as Nigeria.

7.3.2 Methodological contribution

This study made a methodological contribution by using exploratory case study research strategy. In this process, a case study was applied whereby three companies from two different sectors (oil and gas production sector; electricity generation sector) were utilized. Consequently, data triangulation was applied whereby the findings from each company were validated using findings from other companies. Many of the studies that have examined gas flare management particularly in developing countries have focused on single data collection method. However, this study used three data collection methods such as interviews, documentary analysis, and site observation. This process provided more information regarding gas production, utilization and flaring. By using multiple data collection methods, one method complimented the other and provided more details to the root causes of gas flaring in Nigeria.

7.3.3 Practical contributions

This research has made some practical contributions to the area of gas flare management. Based on the findings, a practical framework is proposed using GTW as a technology to manage flared gas in Nigeria. The framework serves as a practical contribution to solving the issue of gas flaring in Nigeria. It serves two major purposes:

- Serves as a clear and easy to use framework to manage gas flaring by converting it to energy.
- An alternative means to contribute towards the national power grid by converting flare gas to electricity.
- Serves as a viable means of reduction of environmental impacts associated to gas flaring.

7.4 PRACTICAL IMPLICATIONS

The results from this research present a number of practical implications for gas flare management and oil and gas production in Nigeria as a whole. Some of these implications have been discussed earlier in chapters 4 and 5 of this thesis. Considering the negative effect of gas flaring on the environment as well as on finances of oil and gas companies, there is need to ensure the necessary measures are put in place by oil and gas production companies to make the best efforts to manage or reduce flared gas. Due to the environmental implication of gas flaring, issues on gas flaring do not only affect the companies involved but also have effects on the environment through pollution. The following practical implications can be deduced from the results of this research:

The first practical implication is that gas flaring is a major problem in Nigeria and needs immediate attention to ensure the excessively flared gas and its effects on the environment is reduced; also to improve the profitability of oil and gas producing companies, particularly in Nigeria. From the results, the problem of gas flaring can be traced to lack of adequate and sustainable technology. For instance in Nigeria, the gas to wire technology is a viable means of gas flare reduction; however, the electricity/power stations are faced with problem of obsolete equipment such as gas turbines. In addition, the practical implication of the results from this research suggests that maintenance of equipment and funding in the power stations are major issues enabling gas flaring. Therefore, improvement of gas utilization could be achieved by solving these challenges.

Another practical implication of the research from this research is that, flared gas can be properly utilized to prevent its negative effects of the environment and a very good use of flared gas can be achieved by using it for electricity production. Though this utilization comes with initial financial obligation and resource demands, the costs involved in the utilization of flared gas can be recovered over time from the revenues generated from the use of the electricity. Considering electricity supply is a major problem in Nigeria, the proposed framework presents a viable option for the nation to reduce the problem of electricity supply. GTW is not just expected to reduce the problem of electricity but also prevent the pollution of the environment from flared gas, which is a national issue.

Considering the widespread location of flare sites in Nigeria, the implication of the results from this research is that it will be more expensive and practically non-economical to use a single gathering system to get all the flared gas from the gas production companies to one location. For this reason, a multiple gas gathering system is also proposed to gather the yearly flared gas of 18.27 BCM into a prime station and then used for electricity generation.

The unavailability of such framework or its adoption in Nigeria can be linked to the fact that this form of research has not been carried out or such a framework ever been proposed for adoption in the country. Furthermore, lack of large-scale application of GTW in Nigeria could be linked to lack of fund to effectively finance about 50 units of gas turbines, as well as lack of appropriate and adequate management on the part of the electricity generation companies.

7.5 THESIS CONCLUSION

The act of gas flaring has become a part of crude oil exploration, which has been allowed to exist despite the adverse impacts that it is associated with. It has been minimized significantly in some western oil producing countries like Canada and Norway, while it has continued to pose huge threat to environment, economy and health of oil and gas producing countries such as Nigeria and Russia and the world at large. About 100 Billion Cubic Meters (BCM) of gas is being flared globally on an annual basis, with Russia and Nigeria flaring more than other countries to the tunes of 35.5 and 18.27 BCM, respectively.

During the process of review of literature, it was identifies that Nigeria is the 6th largest oil producer in the world (EIA, 2013), 8th largest producer of natural gas (Ite and Ibok, 2013), and also has an estimated proven natural gas reserve of 5.3 trillion billion meters. However, literature also reveals that Nigeria also suffer from poor electricity generation. Nigeria's daily electricity demand is estimated to be about 12000 MWh, while the electricity production is 4358 MWh per day; this depicts 36.32% of the overall daily need of electricity capacity of the country. Hence, the focus on use of GTW technology for the management of flare gas. Furthermore, review of relevant literatures helped the study to identify three prime gaps in knowledge in the area of study such as lack of existing gas flare management framework in Nigeria, lack of economic evaluation of GTW technology for gas flare reduction and, lack of cordial relationship and understanding between oil and gas producing/flaring companies and electricity producing sector for flare gas management.

To achieve the aim of this study, which is to develop a framework, whose adoption would lead to further utilization of flare gas by conversion to gas to electricity and other technologies. The qualitative research design was applied, and the multiple case study design was chosen, where data related to volume of gas production, utilization and flaring were collected from an oil and gas producing organisation and two electricity generating organisations in Nigeria. These data were collected through structured semi interviews. Five (5) experts each from the chosen case studies were interviewed and this provided the study with valuable information on gas production, utilization and flaring scenarios in Nigeria; also the electricity generation and challenges, as well as potential solutions were identified. Subsequently, the collected data were analysed using QSR data analysis software version NVIVO10.

Having identified and chosen GTW technology as a sustainable means for gas flare management, the study therefore, carried out an economic assessment on GTW technology. This is to investigate the financial implication of using gas turbines to minimize gas flaring, thereby showing the cost and effect of utilizing the technology for flare gas management. The result showed that that GTW technology is economically sustainable and viable. An estimated capital investment of £1.64bn into 50 units of gas turbine of 150 MW capacity per unit is expected to generate an annual net profit of £1.26bn.

Finally, a framework for management of flare gas was developed. It frameworks the utilization of flare gas and acts as a tool for significant reduction of gas flaring. This framework is expected to encourage improved economy, improved environment and improved health within and outside the gas flare environments when properly put to use. Subsequently, the framework was validated by experts in the oil and gas sector as well as from the electricity production sector. The face validity process was used, where semi structured interviews were carried out on six experts from three companies. The validation process was carried out to show the credibility of the framework. This process led to the modification of the framework for flare gas management. Real figures from Nigerian gas production, utilization and flaring were inputted into the framework. The Results from the framework suggest that the annual gas flare in Nigeria could be reduced from 18.27 BCM to 1.3 BCM.

7.6 REFLEXIVITY

The past four years that I have invested in achieving a Ph.D. degree have been very intense in terms of academic knowledge and have positively affected my entire life. This journey has been like a roller coaster – there have been the challenging times, the trying times and of course the good times; but very importantly, this journey has taught me how to endure, focus and believe.

A very important aspect of this journey was the fact that I was lucky to have an experienced and understanding supervisory team, which guided and supported me throughout the whole processes. The journey to achieving a Ph.D. degree has stretched and expanded my intellectual capabilities and has also equipped me on how to conduct a study independently. I now have a better understanding of research process and academic writing, and above all, I have learnt so much within this period, even in non-academic related issues. Finally, it is good to say that this was a difficult task; however, it was worth it at the end.

7.7 SUMMARY

This chapter has presented the conclusion for this research and has provided a summary of how the aims and objectives of this research were achieved. The chapter has also presented the conclusions and implications of the findings of this research generally to gas flaring in Nigeria and other developing countries with similar problems of gas flaring. The chapter has also made a number of recommendations for the oil and gas industry as well as for reducing the problem of electricity generation in Nigeria. This chapter has also shown the contributions of this research to theory and practice. As shown in this chapter, this research contributes both to the advancement of knowledge on the issue of gas flaring and the management of gas flaring especially the use of GTW as a viable means to manage flare gas.

In addition, this chapter also discussed the limitation of this research and made recommendations for further studies.

CHAPTER EIGHT: SUGGESTED FUTURE RELATED-RESEARCH

There could hardly be any research without limitations. Therefore, as other researches have encountered, this research had a number of limitations that need to be addressed. Subsequently, the findings of this research and research limitations have resulted in the identification of potential future research within the area of gas flare management. These recommendations include the following:

1. This study was limited to oil and gas producing companies and electricity generation companies in Nigeria. It is the researcher's belief that although the research was limited to few organizations, nonetheless, most of the research findings are most likely to be similar in other parts of the globe with related issues of gas flaring and, possibly poor electricity generation. However, it is apparent that national problems vary in terms of social developmental needs, infrastructure and technology; therefore, further research based on different countries of different social need could also be carried out to identify which gas flare management technology specifically suits such areas.
2. Due to the adverse effects associated with gas flaring, it is imperative to evaluate and determine their impacts on the local communities. This study recommends that a further study be carried out within a specified radius/perimeter of flare sites in gas producing and flaring communities. This could help to determine the levels of severity of the impacts of flared gas depending on distance from flare sites.
3. Apart from GTW technology, other technologies could also be applicable for management of flared gas as rightfully shown in the proposed framework for flare gas management. Therefore it is recommended that an economic assessment be carried out on other technologies such as liquefied natural gas (LNG), gas to methanol, gas to liquid (GTL) in Nigeria. This could be vital in determining the most economical gas flaring technology for Nigeria.
4. Concerning the proposed framework for gas flare management, the recommendation is that a further exploration be carried out to identify various locations of flare sites in Nigeria. This could help to determine if more prime stations for gas gathering are required. This further study will also carry out a thorough financial evaluation for flared gas gathering using the multiple gas gathering system as recommended by this study to identify if it is economically feasible.

REFERENCES

Abdulai, R.T. (2010). Traditional Landholding Institutions in Sub-Saharan Africa - The Operation of Traditional Landholding Institutions in Sub-Saharan Africa: A Case Study of Ghana. Saarbrücken: Lambert Academic Publishing AG & CO KG.

Abdulkareem, A. S., and Odigure, J. O. (2006). Deterministic Framework for Noise Dispersion from gas Flaring: A case study of Niger–Delta area of Nigeria. Chemical and biochemical engineering quarterly, 20(2), 157-164

Adekola, O., Mitchell, G., Grainger, A (2015) Inequality and ecosystem services: The value and social distribution of Niger Delta wetland services. Ecosystem Services 12, 42-54.

Agboola, O.M., Nwulu, N.I., Egelioglu, F., Agboola, O.P. (2011) Gas Flaring in Nigeria: Opportunity for Household Cooking Utilization. International Journal of Thermal and Environmental Engineering, 2 (2), 69-74.

Aghalino, S.O (2009) Gas Flaring, Environmental Pollution and Abatement Measures in Nigeria, 1969-2001. Journal of Sustainable Development in Africa, 11, 4, 219-238.

Ahmed, A., Roddy, D., Roskilly, T., Bilotkatch, V., Wang, Y.D. (2015) Analysis of Levelised Gas Transportation Cost in Nigeria. International Kournaal of Business and Management Study, 2, 1, 164-170.

Ahmed, M.M., Bello, A.A., Idris, M.N. (2012) Natural Gas Utilization And The Nigerian Gas-To-Liquid Project; An Opportunity To End Gas Flaring. International Journal of Emerging Trends in Engineering and Development 2, 2 240-256.

Ahmed, M.M., Bello, A.A., Idris, M.N., 2012. Natural gas utilization and the Nigerian gas-to-liquid project; an opportunity to end gas flaring. International Journal of Emerging Trends Eng. Dev. 2 (2), 240-256.

Ajiboye, J.O., Ajiboye, J. O. Adu, E.O. and Wojuade, J. I. (2007) Stakeholders' Perception of the Impact of GSM on Nigeria Economy: Implication for Emerging Communication Industry. Journal of Information Technology Impact, 7 (2), pp. 131-144.

Ajugwo, A.O. (2013) Negative Effects of Gas Flaring: The Nigerian Experience. Journal of Environment Pollution and Human Health 1(1) 6-8.

Akachidike, K. (2008) Remote Stranded Gas-Challenges and Opportunities for Development: Proceedings of the 38th Annual Conference of NSChE, Effurun, Delta State, Nigeria.

Akinwunmi, A., Gameson, R., Hammond, F. and Olomolaiye, P. (2008) The Effect of Macroeconomic Policies on Project (Housing) Finance In Emerging Economies. First International Conference on Construction In Developing Countries (ICCIDC–I).

Aliyu, A.S., Ramli, T.R., Saleh, A.S (2013) Nigeria Electricity Crisis: Power Generation Capacity Expansion and Environmental Ramifications. Energy 61, 354-367.

Amaeshi, K., Amao, O.O (2009) Corporate Social Responsibility in Transnational Space: Exploring Influences of Varieties of Capitalism on Expression of Corporate Codes of Conduct in Nigeria. Journal of Business Ethics, 86, 225-239.

Ana, G. R. (2011). Air Pollution in the Niger Delta Area: Scope, Challenges and Remedies. The Impact of Air Pollution on Health, Economy, Environment and Agricultural Sources, 182-198.

Anderson, K., and McAdam, R. (2004) A Critique of Benchmarking and Performance Measurement: Benchmarking. An International Journal, 11(5), pp.465-483.

Anejionu, O.C.D., Ahiarammunnah, P.N., Nri-ezedi, C.J (2015) Hydrocarbon pollution in the Niger Delta: Geographies of impacts and appraisal of lapses in extant legal framework. Resources Policy 45, 65-77.

Anomohanran, O., (2012). Determination of greenhouse gas emission resulting from gas flaring activities in Nigeria. Energy Policy, 45, pp.666-670.

Anyadiegwu, C.I.C, Muonagor, C.M, Nnakaihe, S.E (2014) Comparative Economic Analysis of Using Natural Gas For Liquefied Natural Gas Production and Converting Natural Gas To Diesel Through Gas-To-Liquid Technology In Nigeria. International Journal of Research in Engineering and Science, 2(9), 9-26.

Augustine, O.I., Sanford, W.W. (1976). The Effects of Waste Gas Flares on the Surrounding Vegetation in South-Eastern Nigeria. Journal of Applied Ecology, 13, 1, 177-187.

Babbie, E. (1990). Survey Research Methods (2nd Edn.). Belmont, California: Wadsworth Publishing Company.

Bahadori, A. (2014). Air Pollution Control. In Pollution Control in Oil, Gas and Chemical Plants (pp. 1-117). Springer International Publishing.

Bailey W, Crabree M, Tyrie J, Elphick J, Kuchuk F, Romano C, Roodhart C (2000) Water Control; Oil field review: Shell International Exploration and Production Newsletter, 70:17-19.

Bailey, C. A. (2007) A Guide to Qualitative Field Research. 2nd ed. London: Pine Forge.

Bannock, G., 2005. The economics and management of small business: an international perspective. Psychology Press.

Barnes, D (2001) Research Methods for the Empirical Investigation of the Process of Formation of Operations Strategy. International Journal of Operations and Production Management. 21(8), pp. 1076-1095.

Barone, T.E. (1992). On The Demise of Subjectivity in Education Inquiry. Curriculum Inquiry, 22, 25-38.

Bassey, N. (2008) Gas Flaring: Assaulting Communities, Jeopardizing the World," Proceedings at the National Environmental Consultation, The Environmental Rights Action in Conjunction with the Federal Ministry of Environment, Abuja.

Benbasat, I., Goldstein, D. K. and Mead, M. (1987) The case research strategy in studies of information systems. *MIS Quarterly*, **11** (3), pp. 369-386.

Bjorndalen, N., Mustafiz, S., Rahman, M.H. and Islam, M.R. (2005). No-flare design: converting waste to value addition. Energy sources, 27(4), pp.371-380.

Bogdan, R.C. and Biklen, S.K. (1998). Qualitative Research in Education: An Introduction to Theory and Methods (3rd Edn.). Needham Heights, MA: Allyn and Bacon.

Boyd, R. (1991). Confirmation, Semantics and the Interpretation of Scientific Theories. In: Boyd, R., Gasper, P. and Trout, J.D. (Eds.) The philosophy of science. Cambridge, MA: The MIT Press.

British Petroleum (2012) BP statistical review of world energy.

Broere, W. (2008) The elusive goal to stop flares. Available [Online] from<http://www.shell.com/static/aboutshell/downloads/swol/apr_june_2008/flaring.pdf> Viewed 10/08/2012.

Brooks, F.J (n.d) GE Gas Turbine Performance Characteristics. Available [Online] from <http://up.farsscript.ir/uploads/13316846411.pdf> Viewed 19/10/2014.

Brown, W.L (2014) Review of Paradigms of Research for the 21st Century: Perspectives and Examples from Practice by Antonina Lukenchuck. Education Review, 21.

Bryman, A. (2001) *Social Research Methods.* Oxford, UK: Oxford University Press.

Bryman, A. (2008) Social Research Methods. 3rd ed. Oxford: Oxford University Press.

Bryman, A. and Bell, E. (2007) Business Research Methods. Revised edition, Oxford University Press.

Burney, A. (2008). Inductive and Deductive Research Approach. Lecture conducted from Department of Computer Science from University of Karachi, Sindh.

Burns, A. (2003). Collaborative action research for English language teachers. Ernst Klett Sprachen.

Canadian Centre for Energy Information, Flaring, (2006). Available [Online] from http://siteresources.worldbank.org/EXTGGFR/Resources/5780681258067586081/FlaringQA.pdf

Carbon Trust (2010) Introducing combined heat and power. Available [Online] from < http://www.carbontrust.com/media/19529/ctv044_introducing_combined_heat_and_power.pdf> Viewed 19/10/2014.

Cassell, C. and Symon G. (2004) *Essential guide to qualitative methods in organizational research*. Sage publications. pp. 323- 333.

Celcias (2012) Trying to paint natural gas green. Available [online] from http://www.celsias.com/article/trying-paint-natural-gas-green/ > Viewed 18/10/1012.

Central Intelligence Agency (CIA) (2011) The World Fact Book. Available [online] from https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html Viewed 22/08/2012.

Central Intelligence Agency (CIA) (2013) The World Fact Book [online]. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html [Accessed 8th

Chevron (2015) Nigeria Fact Sheet. Available [Online] from http://www.chevron.com/documents/pdf/nigeriafactsheet.pdf Viewed on 27/10/2015.

CHP Group (2012) Gas-turbine CHP. Available [Online] from http://www.cibse.org/getmedia/efecf2dd-0f48-4ee2-a2fa-25a04818a9f0/Datasheet-3-Gas-Turbines.pdf.aspx Viewed 20/07/2015.

Clarke, A. and Dawson, R. (1999). Evaluation Research: An Introduction to Principles, Methods and Practice. London: Sage Publications Ltd

Collins, C., Oshodi, O. (2010) Improper Abandonment of Oil: Nigerians in America. Available [Online] from http://www.nigeriansinamerica.com/articles/4403/1/Improper-Abandonement-Of-Oil/Page1.html Viewed 10th January, 2017.

Columbia Center on Sustainable Investment (2014) Norway Associated Gas Utilization Study. Available [Online] from http://ccsi.columbia.edu/files/2014/03/Norway-APG-utilization-study-July-2014-CCSI.pdf Viewed 10/08/2015.

Cook, T. D., & Reichardt, C. S. (Eds.). (1979). Qualitative and quantitative methods in evaluation research. Beverly Hills, CA: Sage.

Corbin, J.M. and Strauss, A.L. (2008) Basics of qualitative research: techniques and procedures for developing grounded theory. 3rd ed. ed. Thousand Oaks, Calif.: Sage Publications, Inc.

Creswell, J. W. (1995). Research design: Qualitative and quantitative approaches. Thousand Oaks, CA: Sage.

Creswell, J.W. (2003). Research Design, Qualitative, Quantitative and Mixed Methods Approaches (2nd Edn.). London: Sage Publications.

Creswell, J.W. (2007). Qualitative Inquiry & Research Design, Choosing Among Five Approaches (2nd Edn.). London: Sage Publications.

Creswell, J.W. (2009). Research Design Qualitative, Quantitative and Mixed Methods Approaches, (3rd Edn.). London: Sage Publications.

Crotty, M. (1998) The foundations of social research: meaning and perspective in the research process. Sage Publications.

Crowther, D. and Lancaster, G. (2008) *Research methods: a concise introduction to research in management and business consultancy.* USA: Butterworth-Heinemann.

Daft, R. L. (1983). Learning the craft of organizational research. Academy of Management Review, 8, 539–546.

Darke, P., Shanks, G., and Broadbent, M. (1998). Successfully completing case study research: combining rigour, relevance and pragmatism. Information systems journal, 8(4), 273-289.

Daymon, C. and Holloway, I. (2002) *Qualitative Research Methods in Public Relations and Marketing Communications.* London: Taylor & Francis Books Ltd.

December, 2013].

Denzin, N.K. and Lincoln, Y.S. (1998). Collecting and Interpreting Qualitative Materials. London: Sage.

Denzin, N.K. and Lincoln, Y.S. (2008) *Collecting and interpreting qualitative materials.* Sage.

Denzin, N.K., and Lincoln, Y.S. (Eds.) (2005). The Handbook of Qualitative Research (3rd Edn.). Thousand Oaks, CA: Sage.

Durr, C., Coyle, D., Hill, D., Smith, S. (2007) 'LNG technology for the commercially minded', Gastech 2005, Gastech, Bilbao, Spain.

Dwyer, J. (1993) Outdoor recreation participation: An update on Blacks, Whites, Hispanics, and Asians in Illinois. Managing Urban and High-Use Recreation Settings. USDA Forest Service General Technical Report NC-163, pp. 119-121.

Easterby-Smith, M., Thorpe, R. and Jackson, P. (2008) Management Research, 3rd ed. Sage Publications Ltd, London.

Easton, G. (1992) Industrial networks: a review. In: Axelsson, B. and Easton, G. (eds.), (1992) Industrial networks: a new view of reality, Routledge, London, pp. 3-27.

Economides, M.J (2005) Economics of Gas to Liquids compared to Liquefied Natural Gas. World Energy Magazine, 8 (1) 136-140.

Economides, M.J., Fasina, A.O., Oloyede, B (2004) Nigeria Natural Gas: A Transition from Waste to Resource. World Energy 7(1) 134-140.

Edino, M. O., Nsofor, G. N. and Bombom, L. S. (2010). Perceptions and attitudes towards gas flaring in the Niger Delta, Nigeria. The Environmentalist, 30, 67-75.

Eisenhardt, K. M. (1989) Building theories from case study research. *Academy of Management Review*, **14**(4), pp.532-550.

Eliseev, O.L (2008) Gas-to-Liquid Technologies. Russian Journal of General Chemistry, Vol. 79(11) 2509-2519.

Ellis, J (2016) Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting. The Alberta Energy Regulator approved this directive on March 22, 2016. Replaces previous edition issued October 5, 2015.

Ellis, L.B. and Crookes, P.A. (2006). Philosophical and Theoretical Underpinnings of Research. In: Crookes, P.A. and Davies, S. (Eds.) Research into Practice; Essential Skills for Reading and Applying Research in Nursing and Health Care (2nd Edn.). London: Bailiere Tindall.

Energy Information Administration, Annual Energy Outlook 2004 with Projections to 2025, U.S. Department of Energy, 2004 (cited in Indriani)

Energy.Gov (2015) Natural gas storage. Available [Online] from http://energy.gov/fe/science-innovation/oil-gas-research Viewed 17/06/2015.

Eni (2015) NAOC Sustainability: Company Profile. Available [Online] from http://www.eni.com/en_NG/eni-in-nigeria/eni-profile/eni-profile.shtml Viewed 27/10/2015.

Environmental challenges of the Niger Delta, Africa: remote sensing-based analyses spanning three decades (1986–2013). Applied Geography 53, 354–368.

ExxonMobil (2015) Nigeria Operations. Available [Online] from http://corporate.exxonmobil.com/ Viewed on 27/10/2015.

Ezigbo, O. (2009) Nigeria: MDGs - Poverty Rate Rises to 76 Percent – UN. Thisday Newspaper. 27th Febuary, 2009. Available [online] from http://allafrica.com/stories/200902270161.html Viewed 22/02/2014.

FOE (Friends of the Earth), Gas flaring in Nigeria, 2004. [E-book] Available from http://www.foe.co.uk. Viewed 18th November, 2016.

Fraenkel, J. R. and Wallen, N. E. (2003). How to design and evaluate research in education. Fifth ed. New York: McGraw-Hill.

Frankfort-Nachmias, C. and Nachmias, D. (1996), Research Methods in the Social Sciences, 5th ed., Arnold, London.

Friends of the Earth International Global Research (2015). New African gas pipeline worries civil society. Available [Online] from https://piazzadcara.wordpress.com/2014/05/10/the-new-west-african-gas-pipeline-2005-nigeria-obama-bring-my-oil-home/ Viewed 12th July, 2015.

Fritzche, M (2005) Combined heat and power

Galliers, R. D (1992) Information systems research: issues methods and practical guidelines. Alfred Waller Ltd publishers, Oxfordshire. pp. 149-152.

Gbenga-Ilori, A. O. and Ibiyemi, T. S. (2010) Directing the Digital Dividend towards Bridging the Digital Divide in Nigeria. European Journal of Scientific Research, 45(1), pp.79-88.

Ghauri, P. and Grønhaug, K. (2005) *Research Methods in Business Studies: A Practical Guide.* 3rd ed. Essex, UK: Pearson Education Limited.

Gillham, B. (2000) *Case Study Research Methods*. London: Continuum.

Giwa, S.O., Oluwakayode, O.A., Olasunkanmi, O.A (2014) Baseline Black Carbon Emission for Gas Flaring in the Niger Delta Region of Nigeria. Journal of Natural Gas Science and Engineering 20, 373-379.

Glaser, B.G. (1978) Theoretical sensitivity: advances in the methodology of grounded theory. Sociology Press, Mill Valley, CA.

Glaser, B.G. and Holton, J. (2004) Reframeworking grounded theory. FQS, 5(2).

Glesne, C. and Peshkin, P. (1992). Becoming Qualitative Researches: An Introduction, New York, NY, Longman.

Golafshani, N. (2003) Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, **8(**4), pp. 597-607.

Grix, J. (2001) Introducing students to the generic terminology of social research. Politics, 22(3), pp. 175-186.

Guba, E.G. (Ed.) (1990) The Paradigm Dialog. London: Sage Publications.

Gubrium, J.F. and Holstein, J.A. (2002) *Handbook of interview research: Context and method.* SAGE Publications, Incorporated.

Hartley, J. F. (1994) Case studies in organizational research. In: *Qualitative methods in organizational research: A practical guide,* edited by Cassell, C. and Symon, G., pp. 209–29. London: Sage.

Hewitt, D.N., Sturges, W.T. And Noa, A, (1995), Global Atmospheric Chemical Changes, Chapman and Hall, New York.

Holden, M. T. and Lynch, M. (2004) Choosing the appropriate methodology: understanding research philosophy [online]. Availabe at: http://repository.wit.ie/1466/1/Choosing_the_Appropriate_Methodology_Understanding_Research_Philosophy_(RIKON_Group).pdf Viewed 22/08/2015.

Huglin, L. M. (2003) The relationship between personal epistemology and learning style in adult learners. Dissertation Abstracts International, 64(03), p.759.

Hunter, T. (2014). Law and policy frameworks for local content in the development of petroleum resources: Norwegian and Australian perspectives on cross-sectoral linkages and economic diversification. Mineral Economics, 27(2-3), pp.115-126.

Ibeanu, O (2000) Oiling the Friction: Environmental Conflict Management in the Niger Delta, Nigeria. Environmental Change and Security Project Report, Issue 6, 19-32.

Igwe, G.J., 2011. Gas transmission/distribution challenges in Nigeria. Business Day. Available [Online] from http://www.businessdayonline.com/NG/index.php/analysis/ Viewed 20/02/2014.

Ikelegbe, A. O. (1993). Pollution in Nigeria: Causes, Effects and Control: The Case of Delta State. Paper presented at the 14th Annual Congress of the Nigerian Geographical Association, Minna, April 18-22.

Imevbore, A.A.A., Adeyemi, S.A. (1981). Environmental Monitoring in Relation to Pollution and Control of Oil Pollution. Proceedings at the Seminar on the Petroleum Industry and the Nigerian Environment, Vol. 6, 1981, pp. 135-142.

IMPAC (2014) Reference Project – Energy Onshore. Afam Integrated Project – Okoloma Gas Plant and Pipelines – Nigeria. Available [Online] from http://www.impac.de/index.php?id=afamintegratedprojectokolom Viewed 12/08/2015.

Index mundi (2015) Nigeria Crude Oil Production by Year. Available [Online] from http://www.indexmundi.com/energy.aspx?country=ng&product=oil&graph=production Viewed 18/08/2015.

Indriani, G. (2005) Gas flaring reduction in the Indonesian oil and gas sector – Technocal and economic potential of clean development ,echanism (CDM) projects. Available [Online] from <http://ageconsearch.umn.edu/bitstream/26096/1/re050253.pdf> Viewed 12/04/2014.

Internet World Stats (2009) Nigeria- Economies, Report [online]. Available [Online] from http://www.internetworldstats.com/af/ng.htm Viewed 16/07/2012.

Internet World Stats (2010) Nigerian Population Stats. Available [online] from http://www.internetworldstats.com/stats.htm Viewed 16/07/2012.

Ishisone, M. (2006) Gas flaring in the Niger Delta: the potential benefits of its reduction on the local economy and environment.

Ismail, O.S., Umukoro, G.E. (2012) Global Impact of Gas Flaring. Energy and Power Engineering, 4,4, 290-302.

Ite, A.I., Ibok, U.J (2013) Gas flaring and venting associated with petroleum exploration in the Nigeria's Niger Delta. American Journal of Environmental Protection, 1, (4) 70-77.

Jahn, M., Michaelowa, A., Raubenheimer S., Liptow, H. (2004) Measuring the Potential of the Unilateral CDM – A Pilot Study. HWWA Discussion Paper No. 263. Hamburgisches Welt – Witschafts – Archiv (HWWA). Hamburg.

Jankowicz, A. D. (2005) *Business Research Projects.* 4th Ed. London: Thomson Learning

Jegede, O. (2002) An integrated ICT-support for ODL in Nigeria. The vision, the mission and the journey so far. Available [Online] from http://www.ukhap.nic.in/ict/docs/s3/jegede.doc. Viewed 22/02/2014.

Jidaw.com (2009) Nigeria: Bridging the Infrastructure Divide [online]. Available [Online] from: http://www.jidaw.com/telecom/telecomm8.html Viewed 18/09/2013.

Jimoh HI, Aghalino SO 2000. Petroleum and Environmental Degradation: A Perspective on Government Policies in Nigeria. In: HI Jimoh, IP Ifabiyi (Eds.): Contemporary Issues in Environmental Studies. Ilorin: Haytee Press, pp. 238-244.

Johnson, R.B. and Onwuegbuzie, A.J. (2004). Mixed Methods Research: A Research Paradigm whose time has come. Educational Research Association, 33(7), 14-26.

Kerlinger, F.N., and Lee, H.B. (2000). Foundations of Behavioural Research (4th Edn.). Philadelphia: Harcourt College Publishers.

Khakee, A. (2003). The Emerging Gap between Evaluation Research and Practice. Evaluation, 9, 340-352.

Klein, H. K. and Myers, M. D. (1999) A set of principles for conducting and evaluating interpretive field studies in information systems. Management Information Systems Quarterly, 23(1), pp. 67-88.

Kuenzer, C., van Beijma, S., Gessner, U., Dech, S. (2014) Land surface dynamics and wnvironmental challenges of Niger Delta, Africa: Remote sensing-based analyses spanning three decades (1989-2013). Applied Geography. 53, 345-368.

Kuhn, T. (1970). The Structure of Scientific Revolutions. Chicago: University of Chicago Press.

Kumar, R (2014) Research Methodology. A Step-by-Step Guide for Beginners. 4th Edition. Sage Publication. London.

Learn Thermo.com (2014) A New Phase Diagram: The T-S Diagram. Available [Online] from < http://www.learnthermo.com/T1-tutorial/ch07/lesson-B/pg08.php> Viewed 20th January, 2015.

Leedy, P. D., and Ormrod, J. E. (2001). Practical research planning and design, 7th Ed., Prentice-Hall, Upper Saddle River, N.J.

Lucko, G., and Rojas, E.M (2010) Research Validation: Challenges and Opportuniies in the Construction Domain. Journal of Construction Engineering and Management 127-136.

Madey, D. L. (1982). Some benefits of integrating qualitative and quantitative methods in program evaluation, with some illustrations. Educational Evaluation and Policy Analysis, 4, 223–236.

Marcecki, J (1988) Combined Heat and Power Generating Systems. Peter Peregrinus limited, London.

Marschan-Piekkari, R. and Welch, C. (2004) Qualitative research methods in IB: the state of the art. In: Marschan-Piekkari, R. and Welch, C. (eds.) Handbook of Qualitative Research. Methods for IB. Cheltenham, UK: Edward Elgar, pp. 5-24.

Marshall, C. and Rossman, G. B. (1999) *Designing Qualitative Research.* 3rd ed. Newbury Park: Sage publications.

Marshall, M. N. (1996) Sampling for qualitative research. *Family Practice*, 13(6), pp. 522-525.

Mayorga-Alba, E., Monge, A., Arrieta, O., Albán, J. and Yépez, H. (2008). The Oil and Gas Sector. Ecuador's, p.125.

Mbendi (2012). Oil and gas in Nigeria – Overview.

Meehl, G.A. (2007) Global climate projection. Climate Change. Available [Online] from < http://wk6kg9sd8m.scholar.serialssolutions.com/?sid=google&auinit=GA&aulast=Meehl&atitle=Global+climate+projections&title=Climatic+change&volume=3495&date=2007&spage=747&issn=0165-0009> Viewed 12th November 2016.

Merriam, S. B. (1997) *Qualitative research and case study applications in education*. Jossey-Bass, Rev Sub Edition.

Middle East Economic Survey (2012) Top five gas flaring countries in 2010. Available (Online) from <http//www.mees.com/en/articles/3207-iraq-s-chalenges-on-its-path-towards-a-world-class-gas-industry> Viewed 23/03/2012.

Miles, M. B. and Huberman, A. M. (1994) *Qualitative data analysis*. 2nd ed. London: Sage.

Miles, M., and Huberman, M. (1984) Qualitative data analysis: An expanded sourcebook. Beverly Hills, CA: Sage.

Miller, S. I., and Fredericks, M. (1991). Uses of metaphor: A qualitative case study. Qualitative Studies in Education, 1(3), 263–272.

Ministry of Energy and Energy Industries (2016) Methanol: Trinidad's Methanol Industry. Available [Online] from http://www.energy.gov.tt/our-business/lng-petrochemicals/petrochemicals/methanol/

Morgan, D. (2007). Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods. Journal of Mixed Methods Research, 1(1), 48-76.

Morse, J. M. and Mitcham, C. (2002) Exploring qualitatively-derived concepts: Inductive-deductive pitfalls. *International Journal of Qualitative Methods*, **1**(4), Article 3.

Mottier, V. (2005) The interpretive turn: History, memory, and storage in qualitative research. *Forum: Qualitative Social Research*, **6**(No.2), pp.2-05.

Mourad, D., Ghazi, O., Nouraddine, B (2009) Recovery of Flared Gas through Crude Oil Stabilization by Multi-staged Seperation with Immediate Feeds: A Case Study. Korean J. Chem. Eng. 26(6), 1706-1716.

Myers, M. D. (2009) Qualitative research in business and management. London, UK: Sage Publications.

Nachmias-Frankfurt, C. and Nachmias, D. (1996). Research Methods in Social Science (5th Edn.). London: Arnold.

Najjar YSH (2000). Gas turbine cogeneration systems: a review of some novel cycles. Journal of Applied Thermal Engineering 20, 179–97.

National Renewable Energy Laboratory (2012) Cost and Performance Data for Power Generation Technologies. Available [Online] from http://bv.com/docs/reports-studies/nrel-cost-report.pdf%E2%80%8E Viewed 18/04/2014.

NaturalGas.org (2013) Combined Heat and Power Systems. Available [Online] from http://naturalgas.org/overview/combinedheat_powersystems/ Viewed 25/07/2015.

NaturalGas.org (2013) Electrical Use. Available [Online] from http://naturalgas.org/overview/uses-electrical/ Viewed 25/07/2015.

NBF News (2011) Why we are investing in independent power plants –Fashola. Available [Online] from http://www.thenigerianvoice.com/nvnews/53449/1/why-we-are-investing-in-independent-power-plants-f.html Viewed 20/04/2015.

Ndoms, E. (2005) Logistics and transportation in oil and gas exploration in Nigeria. Business briefing: exploration and production. The oil and gas review, Issue 2.

Neuman, W.L. (2003) *Social work research methods: Qualitative and quantitative approaches.* Allyn and Bacon.

Newman, I., & Benz, C. R. (1998). Qualitative–quantitative research methodology: Exploring the interactive continuum. Carbondale, IL: Southern Illinois University Press.

Niger Delta Environmental Surveys (1997) Niger Delta Environmental Surveys: Environmental and Socio-economic Characteristics. Environmental Resource Manager Limited, 1.

Nigerian National Petroleum Corporation (2015) Oil Production. Available [Online] from < http://www.nnpcgroup.com/nnpcbusiness/upstreamventures/oilproduction.aspx> Viewed 03/07/2015.

Norwegian Petroleum Directorate (2011). Facts 2011. Available [Online[from http://www.npd.no/en/Publications/Facts/Facts-2011/ Viewed 16/03/2014.

Norwegian Petroleum Directorate (2015) Act 29, No. 72 relating to petroleum activities. Available [Online] from http://www.npd.no/en/Regulations/Acts/Petroleum-activities-act/ Viewed 20/08/205.

Nwaoha, C., and Wood, D.A (2014) A Review of the utilization of Nigeria's natural gas resources: Current realities. Journal of Natural Gas Science and Engineering. 412-432.

Nzewunwa, N. (1979) Ph.D. thesis. Aspects of Economy and Culture in the Prehistory

Oates, B. J. (2006) Researching information systems and computing. Sage Publications Limited.

Obadan, M. I. (2002) Poverty reduction in Nigeria: The way forward. CBN Economic & Financial Review, 39(4) Available [online] from http://www.cenbank.org/out/Publications/efr/RD/2002/efrVol39-4-3.pdf Viewed 12/12/2012.

Odjugo, P.A.O., Osemwenkhae, E.J. (2009). Natural Gas Flaring Affects Microclimate and Reduces Maize (Zea mays) Yield. International Journal of Agriculture and Biology, 11, 4, 408-412.

Odu, C.T.I., 1994. Gas flare Emissions and their Effects on the Acidity of Rain Water in the Ebocha Area. Available [Online] from <https://www.elaw.org/system/files/Ng.GasFlares.AcidRain> Viewed 26/12/2015.

Odularu, G. O. (2008). Crude oil and the Nigerian economic performance. Oil and Gas business, 1-29.

Odumugbo, C.A. (2010) Natural gas utilization in Nigeria: challenges and opportunities. Journal of Natural Gas Science and Engineering 2, 310-316.

Oil and Gas Producers (2000) Flaring and venting in the oil and gas exploration and production industry: An overview of purpose, quantities, issues, practice and trends. Report No 2, 79/288. Available [Online] from < http://www.ogp.org.uk/pubs/288.pdf> 28/10/2012.

Ojijiagwo, E., Oduoza, C.F (2014) The Economics of Gas Flaring in Oil and Gas Processing Environments: A Case Study of Electric Power Station in a Developing Country. 24th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM), San Antonio, Texas. USA

Oluwakiyesi, T (2011) Construction Industry Report: A Haven of Opportunities- Vetiv Research construction sector.

Oni, S.I., Oyewo, M.A. (2011) Gas Flaring, Transport and Sustainability Energy Development in the Niger-Delta, Nigeria. Journal of Human Ecology, 33(1) 21-28.

Onourah, P. (2009) The role of Small and Medium Sized Enterprises for Economic Growth: A Case Study of Matori LGA in Lagos, Nigeria. Master's Thesis, School of Management, Blekinge Institute of Technology.

Onwuegbuzie, A.J., and Leech, N (2005) On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies. International Journal of Social Research Methodology Vol. 8, No. 5, 375-387.

Orimoogunje, O. I., Ayanlade, A., Akinkuolie, T. A. and Odiong, A. U. (2010) Perception on the effect of gas flaring on the environment. Research Journal of Environmental and Earth Sciences 2(4). 188-193.

Orimoogunje, O. O. I., Ayanlade, A., Akinkuolie, T.A., Odiong, A.U. (2010). Perception on Effect of Gas Flaring on the Environment. Research Journal of Environmental and Earth Sciences, 2, 4, 188-193.

Orubu, C.O., Odusola A., Ehwarieme, W (2004). The Nigerian Oil Industry: Environmental Diseconomies, Management Strategies and the Need for Community Involvement. Journal of Human Ecology, 16, 3, 203-214.

Osuoka, A., and Roderick, P. (2005). Gas Flaring in Nigeria. A Human Rights, Environmental and Economic Monstrosity.

Paltrinieri, H., Tugnoli, A., Cozzani, V (2015) Hazard identification for innovative LNG regasification technologies. Reliability Engineering and System Safety 137, 18-28.

Pansiri, J. (2009). Evolution of Doctoral Thesis Research Topic and Methodology: A Personal Experience. Tourism Management, 30, 83 – 89.

Paton, M.Q. (2002). Qualitative Research and Evaluation Methods (3rd Edn.). Thousand Oaks, CA: Sage.

Patton, M.Q. (1990) Qualitative evaluation and research methods. SAGE Publications, Inc.

Penner, J. E. (1999). Aviation and the global atmosphere: a special report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Peters, M.S., Timmerhaus, K.D (1991) Plant Design and Economics for Chemical Engineers. International Edition. McGraw-Hill, New York. USA.

PFC Energy (2007).

Philipp, D.C. and Burbules, N.C. (2000). Postpositivism and Educational Research. Lanham, NY: Rowman and Littlefield.

Pilavachi, P.A. (2000) Power generation with gas turbine systems and combined heat and power. Applied Thermal Engineering 20, 1421–1429.

Ploch, L. (2011) Nigeria: Elections and Issues for Congress. Congressional Research Service, April 1, 2011. Available [online] http://fpc.state.gov/documents/organization/161341.pdf Viewed 10/01/2014.

Ponterotto, J.G (2005) Qualitative Research in Counseling Psychology: A Primer on Research Paradigms and Philosophy of Science. Journal of Counseling Psychology, 52, 126-136.

Poullikkas, A (2005). An overview of current and future sustainable gas turbine technologies. Renewable and Sustainable Energy Review 9, 409-443.

Premium Times (2016). Nigeria is dying, please help us, CNPP urges international community. Available [Online] from < http://www.premiumtimesng.com/news/113214-nigeria-is-dying-please-help-us-cnpp-urges-international-community.html> Viewed 10th September, 2015.

Prentice Hall.

Putnis, P. and Petelin, R. (1996) *Professional Communication: Principles and Applications.*

Quinton, S. and Smallbone, T. (2006) *Postgraduate research in business: A critical guide.* London: Sage.

Rahimpour, M.R., Jamshidnejad, Z., Jokar, S.M., Karimi, G., Ghorbani, A., Mohammadi, A.H. (2012) A comparative study of three methods for flare gas recovery of Asalooye gas refinery, J. Nat. Gas Sci. Eng. 4, 17–28.

Remenyi, D, Williams, B, Money, A, and Swartz, E. (1998) *Doing Research in Business and Management*. Sage Publications: London.

Robson, C. (2002) *Real World Research.* 2nd ed. Blackwell Publishing.

Rolfe, G. (2006) Validity, trustworthiness and rigour: quality and the idea of qualitative research. *Journal of Advanced Nursing*, 53(3), pp. 304-310.

Sapsford, R., Jupp, V (2006) Data Collection and Analysis. 2nd Edition. Sage Publication. London.

Saunders M, Lewis P and Thornhill A (2012): Research methods for business students. 6th Edition, Pearson Education Limited.

Saunders, M., Lewis, P. and Thornhill, A. (2009) Research Methods for Business Students. 5th ed. Prentice Hall: London.

Saunders, M., Thornhill, A. & Lewis, P. (2003) Research Methods for Business Students. 3rd ed. Pearson Education Ltd, Essex.

Schwandt, T. A. (2000). Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics, and social constructionism. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research (2nd ed., pp. 189–213). Thousand Oaks, CA: Sage.

Schwandt, T.A. (2007) The Sage dictionary of qualitative inquiry. Sage Publications, Inc.

Shah, S. K., & Corley, K. G. (2006). Building Better Theory by Bridging the Quantitative–Qualitative Divide. Journal of Management Studies, 43(8), 1821-1835.

Shell Petroleum Development Company of Nigeria (2006) People and environment. Annual report. Available [Online] from http://narcosphere.narconews.com/userfiles/70/2006_shell_nigeria_report.pdf Viewed 10/12/2014.

Shinn, J.H.(2004) Example Potential CDM Projects and Complications: Gas Reinjection and Utilization. Presentation at IPIECA Workshop on Reporting, CDM and JI in Lillehammer.

Shrader-Frechette, K. (1994). Ethics of Scientific Research. New York: Rowman and Littlefield.

Sieber, S. D. (1973). The integration of fieldwork and survey methods. American Journal of Sociology, 73, 1335–1359.

Society of Petroleum Engineers (2012). Annual Oloibiri Lecture Series & Energy Forum: Gas Flare Out, Challenges and The Way Forward. Lagos, Nigeria.

Sonibare, J.A., Akeredolu, F.A. (2006) Natural gas market development for total elimination of routine gas flares in Nigeria's upstream petroleum operations. Energy Policy 34, 743-753.

Stake, R. E. (1995) *The art of case study research*. London: Sage.

Strauss, A. and Corbin, J. (1998) Basics of qualitative research: Techniques and procedures for developing grounded theory. SAGE Publications, Thousand Oaks, USA.

SweetCrude (2017) A Review of the Nigerian Energy Industry: Developing gas pipeline infrastructure in Nigeria: Who is responsible. Available [Online] from http://sweetcrudereports.com/2014/04/07/developing-gas-pipeline-infrastructure-in-nigeria-who-is-responsible/ Viewed 2nd January 2017.

Tashakkori, A., and Creswell, J. W. (2008). Editorial: Mixed methodology across disciplines. Journal of Mixed Methods Research, 2(1), 3-6.

Taylor, S. J. and Bogdan, R. (1998) Introduction to qualitative research methods: A guidebook and resource. 3rd ed. New York: John Wiley & Sons.

Tella, S.A., Amaghionyeodiwe, A. L. and Adesoye, B. A. (2007) Telecommunications Infrastructure and Economic Growth: Evidence from Nigeria. Being a paper submitted for the UN-IDEP and AFEA joint conference on "Sector-led Growth in Africa and Implications for Development" to be held in Dakar, Senegal from November 8-11, 2007. Available [online] from http://www.unidep.org/Release3/Conferences/Afea_2007/IDEP-AFEA-07-17.pdf Viewed 29/03/2012

Tellis, W. (1997) Introduction to case study. *The Qualitative Report*, 3(2). Available [Online] from <http://www.nova.edu/ssss/QR/QR3-2/tellis1.html> [Accessed 12/03/2015].

The Guardian (2015) Nigeria Burns off $5Billion Resources Yearly from Gas Flaring. Available [Online] from http://www.ngrguardiannews.com/2015/11/nigeria-burns-off-5-billion-resources-yearly-from-gas-flaring/ Viewed 18/11/2015.

Thomas, S., Dawe, R.A. (2003) Review of ways to transport natural gas energy from countries which do not need the gas for domestic use. Energy 28, 1461-1477.

Tolulope, A.O (2004) Oil Exploration and Environmental Degradation: The Nigerian Experience. Environ. Inform. Arch. 2, 387-393.

Torgerson, D. (1986). Between Knowledge and Politics: Three Faces of Policies Analysis. Policy Sciences, 19(1) 33-59.

Trading Economics (2011) Nigeria Population. Available [online] from http://www.tradingeconomics.com/nigeria/population Viewed 22/06/2012.

Trading Economics (2016). Nigeria Corporate Tax Rate. Available [Online] from http://www.tradingeconomics.com/nigeria/corporate-tax-rate Viewed 02/05/2016.

Ujumadu, V., 2012. Excitement as Orient Petroleum strikes oil in Anambra. Vanguard Newspaper. 〈http://www.vanguardngr.com/2012/03/excitement-as-orient-petroleum-strikes-oil-in-anambra/#sthash.VHTgOwkC.dpuf〉. Viewed 26/06/2014.

Ukala, E. (2010). Gas flaring in Nigeria's Niger Delta: failed promises and reviving community voices. Washington and Lee Journal of Energy, Climate, and the Environment, 2(1), p.97.

US Energy Information Administration (2013) (Updated December 30, 2013). Available from <http://www.eia.gov/countries/cab.cfm?fips-ni.> Viewed 20/06/2014.

Uyigue, E., Agho, M (2007). Coping with Climate Change and Environmental Degradation in the Niger Delta of Southern Nigeria. Community Research and Development, Centre Benin City.

Walsham, G. (2006) Doing interpretive research. European Journal of Information Systems, 15(3), pp. 320-330.

Werner, A.K., Vink, S., Watt, K. and Jagals, P. (2015). Environmental health impacts of unconventional natural gas development: A review of the current strength of evidence. Science of the Total Environment, 505, 1127-1141.

Williamson, K., Burstein, F. and McKemmish, S. (2002) The two major traditions of research. In: Williamson, K., Research methods for students and professionals: Information management and systems (2nd ed.) Wagga Wagga, Australia: Centre for Information Studies, Charles Sturt University.

Wolcott, H.F. (1994). Posturing in Qualitative Inquiry. In: Le Compte, L.D.; Millroy, W.L. and Preissle, J. (Eds.) The Handbook of Qualitative Research in Education. New York: Academic Press.

World Bank (2004) Flared Gas Utilization Strategy: Opportunities for Small-Scale Uses of Gas. Report 5, World Bank, Washington, DC.

World Population Review (2015) Africa Population 2015. Available [Online] from http://worldpopulationreview.com/continents/africa-population/ Viewed 26/08/2015.

Yar'adua, A.L. (2007) The Nigerian Gas Master Plan, Gas Stakeholders Forum, vol. 1. NNPC, Abuja, Nigeria, pp. 14-15.

Yin, R. K (2003) *Case study research: design and methods.* 3rd Edition, Applied Social Science Method Series. Sage Publications, Thousand Oaks, CA.

Yin, R. K. (2009) *Case Study Research: Design and methods.* 4th ed. Applied Social Science Research Methods, Vol. 5. Sage Publications, Thousand Oaks, CA.

Yin, R. K. (2012). Case study methods.

Yin, R. K. (2013). Case study research: Design and methods. Sage publications.

Yin, R. K. (2015). Qualitative research from start to finish. Guilford Publications.

Zohrabi, M. (2013). Mixed method research: Instruments, validity, reliability and reporting findings. Theory and Practice in Language Studies, 3(2), 254.

APPENDICES

APPENDIX A: INTERVIEW GUIDE FOR OIL AND GAS COMPANY (CASE STUDY COMPANY 1).

School of Technology
University of Wolverhampton
Wulfruna Street
WV1 1LY

Dear Participant,

DEVELOPMENT OF A SUSTAINABLE FRAMEWORK TO MANAGE GAS FLARING IN AN OIL AND GAS ENVIRONMENT: A CASE STUDY OF NIGERIAN.

My name is Emeka Ojijiagwo, a PhD student of the University of Wolverhampton, United Kingdom. As part of my programme, I am carrying out a survey and your participation will be appreciated. Therefore, I would like to invite you to help my research by participating in an interview.

All respondents and their companies are anonymous. If results of this study are published they will only be a summary of all responses to ensure that privacy is protected. Taking part in this interview will be considered as consent to participate in the survey. However, you also reserve the right to opt out any time during the process.

A summary of findings will be available at the conclusion of the study and if you wish to obtain a copy of the results, please provide your contact details. Please note that all data obtained for this research will be stored securely and destroyed only after the dissertation has been submitted.

Thank you. Your participation and contribution are greatly appreciated.

Yours sincerely,

NAME: ………………………………………………………………………………………………

PHONE: +234(0)8146961916; +44(0)7803554757

EMAIL: Emeka.Ojijiagwo@wlv.ac.uk .

<u>DEVELOPMENT OF A SUSTAINABLE FRAMEWORK TO MANAGE GAS FLARING IN AN OIL AND GAS ENVIRONMENT: A CASE STUDY OF NIGERIA.</u>

AN INTERVIEW GUIDE FOR INTERVIEWS CARRIED OUT ON EMPLOYEES FROM AN OIL AND GAS PRODUCTION COMPANY

1. Firstly can you please state your current position and area of specialisation of your company.
2. How does your organisation operate in terms of oil production and activities?
3. This organisation is well known for gas production. So what is the daily capacity of gas production?
4. How many operational oil-well heads and or gas production sites does this company have?
5. As a gas producing firm, do you consistently keep records of volume of produced, utilised, and flared gas?
6. It is understood that this company still flares gas, do you flare all the produced gas or a percentage is flared?
7. Your organisation produces 240 million standard cubic feet (MMSCFD) of gas per day, supplies 220 MMSCFD, and flares 20 MMSCFD as you earlier stated: are the volumes of gas supplied to your clients enough for their daily needs or do they just manage whatever volume of gas provided for them?
8. Do the clients of your organisation utilise all the gas produced? If no, what is the capacity of gas utilised, and what happens to the rest volume of gas not utilised?
9. Why is there still gas flaring instead of sustainably utilised?
10. Does this organisation intend to mitigate the routine gas flaring that takes place in the site?
11. As a senior employee of this organisation, what form of technology will you suggest for the management or prevention of gas flaring in this site as well as other flaring sites in Nigeria?
12. : In your personal view, do you think the gas that is flared in your organisation is avoidable?

13. What challenge or challenges do gas production organisations face with regards to tackling and managing gas flaring?
14. In your view, do you think the gas production organisations need any form of support from the government?
15. Electricity companies currently utilise the gas produced by your company and your company still flare gas. Do you still believe Gas to Electricity technology is still capable of significantly reducing gas flaring in Nigeria?
16. Does this organisation have any suggestion(s) that could be beneficial to the management and reduction of gas flaring globally?
17. In your view as an experienced member of staff of this organisation, what are your suggestions towards gas flaring reduction/management?
18. In some western countries like Norway and Canada, governments encourage production companies to minimise In your view, do you think the gas production organisations need any form of support from the government?
19. This research aims at providing a framework for management of flare gas. It hopes to provide processes and financial implication towards this. So, will this organisation embrace such an output to support the reduction of gas flaring?

APPENDIX B: INTERVIEW GUIDE FOR ELECTRICITY PRODUCING COMPANIES (CASE STUDY COMANIES 2 AND 3).

School of Technology
University of Wolverhampton
Wulfruna Street
WV1 1LY

Dear Participant,

DEVELOPMENT OF A SUSTAINABLE FRAMEWORK TO MANAGE GAS FLARING IN AN OIL AND GAS ENVIRONMENT: A CASE STUDY OF NIGERIAN.

My name is Emeka Ojijiagwo, a PhD student of the University of Wolverhampton, United Kingdom. As part of my programme, I am carrying out a survey and your participation will be appreciated. Therefore, I would like to invite you to help my research by participating in an interview.

All respondents and their companies are anonymous. If results of this study are published they will only be a summary of all responses to ensure that privacy is protected. Taking part in this interview will be considered as consent to participate in the survey. However, you also reserve the right to opt out any time during the process.

A summary of findings will be available at the conclusion of the study and if you wish to obtain a copy of the results, please provide your contact details. Please note that all data obtained for this research will be stored securely and destroyed only after the dissertation has been submitted.

Thank you. Your participation and contribution are greatly appreciated.

Yours sincerely,

NAME: …………………………………………………………………………………………

PHONE: +234(0)8146961916; +44(0)7803554757

EMAIL: Emeka.Ojijiagwo@wlv.ac.uk .

<u>DEVELOPMENT OF A SUSTAINABLE FRAMEWORK TO MANAGE GAS FLARING IN AN OIL AND GAS ENVIRONMENT: A CASE STUDY OF NIGERIA.</u>

AN INTERVIEW GUIDE FOR INTERVIEWS CARRIED OUT ON EMPLOYEES FROM ELECTRICITY GENERATING COMPANY

1. Firstly can you please state your current position and area of specialisation of your company?
2. As a key employee of an energy generation company, could you please say more on electricity production in your company – electricity generation and distribution?
3. It is understood your company utilises gas turbine, and at such uses gas, could you state more on your source of gas supply? This could include expected volume of supply and actual volume of supply.
4. How does your company cope with situations arising from insufficient or lack of gas supply from your suppliers?
5. How many gas turbines does this company have in total?
6. How many are operationally effective and how many are not?
7. What is the daily average volume of gas needed by the gas turbines?
8. As a company with the responsibility of producing energy for Nigeria, is there any form of alternative source of gas supply apart from the current supplier – Okoloma Gas Plant?
9. Can you elaborate more on the typical problems facing the turbines in your company?
10. How often do you carry out maintenance of the turbines and can you give more details of the processes and procedures involved?
11. Does this company have any back up plan regarding emergency breakdown of equipment such as gas turbine?
12. Could you please explain how the generated electricity is distributed from your company?
13. Considering the fact that Nigerian power stations as a whole generate less amount electricity than needed on a daily basis, and also considering your position and experience in the energy sector, please what strategies could you recommend to improve electricity generation, bearing in mind the challenges facing the power stations?

14. Apart from money generated from sales of electricity, are there other means of money generation by this company? Please highlight more on those sources.
15. What challenge or challenges do gas production organisations face with regards to tackling and managing gas flaring?
16. In your view, what are the areas that the power stations need help from external sources like government to help improve electricity generation?
17. Primarily, his research aims at providing a framework for management of flare gas. However, intends to apply gas to electricity technology as a means of gas utilisation to avoid severe gas flaring. The study also hopes to provide processes and financial implication towards this. So, do you think that your organisation will embrace such an output to support the reduction of gas flaring?

APPENDIX C: CONFERENCE PAPER DEVELOPED FROM THE STUDY.

The Economics Of Gas Flaring In Oil And Gas Processing Environments: A Case Study Of Electric Power Station In A Developing Country

Emeka Ojijiagwo*, Chike F. Oduoza
Faculty of Science and Engineering
University of Wolverhampton
Wolverhampton, WV1 1LY, United Kingdom.

ABSTRACT
Gas flaring continues to pose significant threat to the environment and economy of oil and gas producing countries in particular and the globe in general. This process impacts adversely to the health and safety of the inhabitant of these countries. About 100 Billion Cubic Meters (BCM) of gas is being flared globally on annual basis with Russia and Nigeria flaring more than other countries to the tune of 35.5 and 15.2 BCM, respectively. During oil and gas processing, excess gas that is generated could be managed and beneficially harnessed by systematic channelling of the gas to the power sector where turbines utilize it to generate power. The aim of this study therefore is to investigate the production, distribution, consumption and wastage/misuse of associated gas in a typical gas-processing environment to find out the cost and effect of gas flaring. The methodology adopted to gather data involves case studies, interviews, questionnaires, artefacts and observations. The investigation site has seven gas production wells with an output of 7.2 million cubic meters per day (mmcmd). While 91.7% of this output is supplied to customers for consumption, the remaining 8.3% is controllably flared. The flared quantity increases with reduction in customers' demand and during production down time. It was found in the investigation that an average power station comprising three gas turbines and one steam turbine utilises about 3.0 mmcmd of gas to generate approximately 600-650MW of electricity. Consequently, this research proposes that with the employment of an additional gas turbine, substantial quantity of the flared gas could be sustainably used to generate power if the flaring process is properly managed.

KEYWORDS: *Gas Flaring; Electricity generation and distribution; Power station; Financial Cost*

* Corresponding Author: (+44) 7803554757; E-mail: Emeka.Ojijiagwo@wlv.ac.uk

APPENDIX D: CONFERENCE PAPER DEVELOPED FROM THE STUDY.

Gas-To-Wire As A Way Of Bridging The Energy Gap In A Developing Country

Emeka Ojijiagwo*, Chike F. Oduoza, Nwabueze Emekwuru.
Faculty of Science and Engineering
University of Wolverhampton
Wolverhampton, WV1 1LY, United Kingdom

ABSTRACT

Sufficient production and supply of energy could guarantee improved economy. In most African countries, governments control electricity production and distribution: particularly in Nigeria where, the Power Holding Company of Nigeria (PHCN) is totally in charge of distribution and responsible for most productions. Nigeria's daily electricity demand is estimated to be about 12000 MWh. PHCN has total installed daily capacity of 6904.6 MW, of which 3358 MWh is produced at peak operation; while the Independent Power Producers (IPPs) generate 1000 MWh. This depicts 36.32% of the needed energy capacity of the country; signifying urgent need for improved electricity generation. With annual natural gas production of 2.6 trillion cubic meters (TCM), and an estimated 4.3 TCM by the year 2025, Nigeria could channel its electricity generation attention towards gas-to-electricity as the potential solution. This study aims to bridge the gap between energy demand and production in developing countries like Nigeria that have crude oil and gas reserves. This paper is a case study of Nigerian electricity production, as well as the associated challenges in the electricity sector. Interviews were conducted on officials and stakeholders of the PHCN, particularly from the Afam Power Station, and relevant data were collected in the process. This paper established that in a typical Nigerian gas-fired power station, 0.93 million cubic meters (MCM) of gas is needed to effectively operate a gas turbine unit that generates 150 MWh. This is equivalent to 1.25% of the Nigerian daily electricity demand, and this percentage increases with more units of gas turbine.

*Corresponding Author: Tel.: (+44) 7803554757; Email: Emeka.Ojijiagwo@wlv.ac.uk

APPENDIX E: JOURNAL PAPER DEVELOPED FROM THE STUDY.

ECONOMICS OF GAS TO WIRE TECHNOLOGY APPLIED IN GAS FLARE MANAGEMENT

Emeka Ojijiagwo *[a], Chike, F. Oduoza [a], Nwabueze Emekwuru [b]

[a,] Faculty of Science and Engineering. University of Wolverhampton. WV1 1LY, Wolverhampton, United Kingdom.

[b,] Faculty of Engineering. Coventry University. CV1 5FB. Coventry. United Kingdom

ABSTRACT

Our environment is increasingly being endangered by the introduction of greenhouse gases which are continuously produced from gas flaring processes. Currently, total volume of gas flared globally amounts to 100 Billion Cubic Meters (BCM) annually. Nigeria flares about 18.27 BCM and loses approximately $2bn yearly. This statistics indicates the urgent need to conduct research aimed at addressing both the environmental impact of gas flaring and the economic implications. This research studies the economic viability of using gas to wire (GTW) technology as an integral component of gas flare management. The investigation critically evaluates the cost implications and impact of the GTW technology. The research method involves the interview of key experts and practitioners in the field. The interviews are structured to obtain information on the total volume of gas produced, utilised and flared in two major gas and electricity producing firms in Nigeria. The data obtained show that the gas producing company flares about 8.33% of its total production which is in excess of the 6.6 million cubic meters (MCM) utilised daily. This study demonstrates that in the Nigerian oil and gas sector, one unit of gas turbine having 0.93 MCM gas consumption capacity generates 150 MW of electricity daily. It is found in result evaluation that 50 turbines are sufficient to consume an average of 46.5 MCM of gas daily to generate 7,500 MW of electricity. Economic analysis shows that there is an annual net profit of £2.68bn gained from flare prevention and overall environmental protection.

KEYWORDS: Gas Flare Reduction; Gas-to-wire Technology; Economic Valuation; Power Generation.

* Correspondent Author

Email address: Ojijiagwo@yahoo.com (Emeka Ojijiagwo)

APPENDIX F: ETHICS APPROVAL FORM

UNIVERSITY OF WOLVERHAMPTON
SCHOOL OF TECHNOLOGY
ETHICAL CONSIDERATION FOR RESEARCH PROGRAMMES

Section 1: Your details			
First Name & Surname:	Emeka Ojijiagwo	**Student No:**	1133443
Project Title	Development of a sustainable framework to minimise gas flaring in an oil and gas environment: a case study of Nigeria.		
Director of Studies:	Prof. Chike F. Oduoza		

Section 2: Your Project Topic	
2.1 What problem is this project addressing? (100 words or less) In the process of routine operations that are involved in the production of oil and gas, there is a controlled system that involves the burning of associated gas. This is known as GAS FLARING. Gas flaring is associated with environment impact, economic waste and health hazards. Therefore this research hopes to proffer a good gas flaring management framework, which will help to reduce the quantity of gas that is flared, and therefore minimise the adverse impacts that are associated with it.	
2.2 Will information or artefacts resulting from your project be available externally to the University?	Yes
2.2.1 **If you answered 'yes' to 2.2,** will any such information place anyone at risk or possibly result in any action that might be detrimental	No. Information obtained is strictly for academic purposes and poses no risk to the well- being of participants as stated in Section 1: Category A1 of the ethics

to their wellbeing? (See guidelines)	approval guidelines. Electronic copy of dissertation to be kept in the learning centre and could be accessed by others but no confidential information, such as transcribed excerpts will be included.
2.2.2 in what format will the information or artefacts be made available?	Databases such as Ethos and WIRE, conference proceedings and Publications in academic journals.

Section 3: Method of Data Collection	
Please attach samples with this form if you intend to do interviews, surveys, or questionnaires.	
3.1 Does any part of your proposed project involve human participants?	Yes **If 'no' proceed to section 4**
3.2: Please explain any aspects of the project, which might be detrimental to the wellbeing of any human participants in your project.	
Regarding the questionnaire and interview, the researcher envisages that there might be a degree of risk of animosity from the respondents/participants if their responses are made public to the local or international press. Thereby this might lead to clash of interests, which could lead to restiveness in the community and even among workers in same or different companies. Therefore, to address this problem, firstly, the researcher will inform the participants through writing and verbal information (for less educated community participants) about the meaning and limits of confidentiality. This will help the participants to understand that every information they give is strictly for this research and will not be disclosed outside this research. High level of carefulness will be put into practice by the researcher. And to such effect, the ANONYMITY TYPE 4 will be utilised: this will involve the participants being referred to by pseudonyms in any	

form of publications that will result from this research. The researcher intends to remove identification numbers from questionnaires after they are returned; and regarding the interviews, the researcher intends to ask the respondents to make use of personal aliases. And with regards to the preparation of the data for analysis, the researcher intends to separate identifying information from the data itself.
3.3: Are there other ways you might meet your project aims without involving human participants? If not, why?
No. This is because this project intends to find out the reason(s) for continuous gas flaring in the oil and gas business sector directly from the Organisations that are involved in the gas flaring; and also find out the impact of gas flaring from those who are directly affected. And these information will be obtained from practical participation of humans.
3.4: How will you select your participants?
The participants for this survey are selected from the oil and gas operators, Oil and Gas Producing Communities and the Government. From the operators, the employees who are responsible for crude oil production operations will participate, and the managers will also be participating. In the oil producing communities, the community leaders (chiefs, women leaders and youth leaders) will be targeted. And from the government, the senior staff of Rivers State Environmental Agency and Department of Petroleum Resources (DPR) are the participants. However, the government agencies will ONLY be involved in the focus group discussion. Therefore, selected representatives from the above-mentioned groups will be utilised for the survey.
3.5: How many participants will you contact?
INTERVIEW: Thirty (30) participants **This number of potential participants are chosen because we expect that the response rate might not be very high**
3.6: How will you approach potential participants? E.g. email, letter, face to face? Please append text of any letter or email

<table>
<tr><td colspan="2">

1. Letter: The questionnaires will be dispatched to the respondents (operators, host communities) though post office delivery and hand post, depending on the distance and level of understanding of English language of the respondents. The researcher will do the latter personally because, he could communicate with the community representatives that could not speak and write good English language. In this case, the researcher will interact with them in their local dialect.
2. Email: The oil and gas producing firms will be contacted through email to notify them about the survey. And subsequently, questionnaires will be sent out to some respondents through same means.
3. **3.** Face to Face: The interviews, including the focus group discussion (on oil and gas operators, government agencies) will be carried out through face to face. This will come after preliminary processes like fixing of dates, times and venues have been earlier concluded through emails, letters and phone calls. The participants from the oil and gas producing communities will be contacted through the community Chiefs. This method will also be used during the questionnaire session for the oil and gas producing community representatives.

</td></tr>
<tr><td colspan="2">3.7: Are your participants adults? (over 18 and competent to give consent) If no, answer 3.7.1. (See guidelines)

Yes/~~No~~?</td></tr>
<tr><td>3.7.1: Are your participants children or adults over 18 and not competent to give consent? If yes, why is it necessary to involve these participants?</td><td>No.</td></tr>
<tr><td>3.8: Are you offering any incentives to any of your participants, financial or otherwise? (See guidelines)</td><td>No?</td></tr>
<tr><td>3.9: How much time do you estimate will be needed from any participants? (See guidelines)</td><td>Interview: Average of 35 minutes</td></tr>
<tr><td colspan="2">3.10: Please list the method of data collection and analysis intended to be used

<u>Data collection method:</u>

1. Interview</td></tr>
</table>

2. Case studies 3. observation Data analysis method:. ➢ Analysis of the survey (interview and questionnaire) data would involve categorization, pattern identification and theme creation through the Nvivo Software. ➢ Statistical Processes for Social Science (SPSS) tools will be used to identify correlations, regressions and importance of the attributes investigated.

3.11: Will all of the data collected contribute towards your results?	Yes.

Section 4: Confidentiality and data handling	
Please read methods of ensuring confidentiality in the guidelines.	
4.1 Will you ensure the anonymity of data collected from/and about participants?	Yes
3.1.1 Please explain how this will be achieved.	
The 'Type 4' Anonymity method will be used. The real names of the participants shall not be used in any form. Rather, this will involve the participants being referred to by pseudonym in any publication arising from the project.	
4.2 Will you store/protect data collected from individuals e.g. password protected files?	Yes
4.3 Once your project is complete and information is no longer needed, will you destroy your data?	Yes
4.4 Will anyone else have access to the data collected?	Yes

If so, (i) please name the individuals and/or groups that will have access; (ii) why is access being given to those listed in (i)?	1. Professor Chike Oduoza (Research Director of Studies). 2. Professor Richard Hull (Research supervisor) They will be accessible to the data because they in the supervisory team, and therefore a part of the research.

Section 5: Working with other parties and companies	
5.1 Will you be using data on subjects held by another party or organisation?	Yes
If Yes, (i) Please give details. (ii) How will you gain access to this information?	(i): during case study, data will be collected from two (2) organisations in the oil and gas sector. (ii): Arrangements have been made and concluded with some senior management staff for access into some of their organisations' data.
5.2 Do you require written permission from a company, organisation or location, e.g. an employer or local authority?	No
If Yes, (i) Please complete an <u>external agreement form</u> and include this with your submission.	
NB: If working with another organisation or company please familiarise yourself with their	

Health & Safety procedures.

Things you must be aware of:

Data Protection Act: http://www.ico.gov.uk/what_we_cover/data_protection.aspx

Freedom of Information Act: http://www.opsi.gov.uk/Acts/acts2000/ukpga_20000036_en_1

University of Wolverhampton Ethical Approval Procedural Guidelines

Checklist:

1. If you are using a questionnaire or interview sheet please include a list of sample questions with your submission.
2. In addition, please include an introductory cover letter stating some information about you, your project proposal and how your data will be used.
3. If you are undertaking a project involving a company or organisation you will need to show that you have approval from that organisation. Please include a completed copy of the External Agreement Form.

Student's Declaration Sign and date against **one** declaration **only**	
Category 0. My project involves no human participation except for myself and I agree to ensure that any information or artefact produced will not be available outside the University.	
Category A1. My project involves limited human participation and I agree to ensure that (i) any such participation is not detrimental in any way to the interests of the participants; (ii) all information collected as a part of the project will be handled in accordance with the answers that I gave to question **4**; (iii) No information or artefacts which may place anyone at risk or be detrimental to their wellbeing will be made available outside the University.	Emeka Ojijiagwo 15/06/2013.
Category A2. My project involves human participation and may present some risk to participants. I have considered alternative means of pursuing the project which do not entail this risk but believe that there is no practicable alternative. I agree to ensure that I take all necessary steps to minimise risks to participants and third parties. I agree not to proceed with any activities involving human participation until I have received approval from the Department Ethics Panel.	
Category B-E. My project does not conform to Category 0, A1 or A2. I have considered alternative means of pursuing the project which do not entail risk to human participants but believe that there is no practicable alternative to the proposal made. I agree to ensure that I take all necessary steps to	

minimise risks to participants. I agree not to proceed with any activities involving human participation until I have received approval from the School or University Ethics Committee, as appropriate.	

Director of Studies/Principal Investigator's Declaration Sign and date against **one** declaration **only**	
Category 0 or A1. I concur with the classification of this project as **0** or **A1** and authorise continuation of the project pending consideration by the School Ethics Committee	
Other. I believe that this project should be classified other than **0** or **A1.** I will ensure that no activities involving human participants take place until and unless approval is granted by the School Ethics Committee	

FOR SUPERVISOR/PANEL/COMMITTEE USE ONLY:

CLASSIFICATION ALLOCATED BY SUPERVISOR						
0, A1		**Supervisor Action:** Authorise and forward to SEC	Date			
Othe r		**Supervisor Action:** Refer to DEP for decision	Date			
	CLASSIFICATION ALLOCATED BY SCHOOL ETHICS COMMITTEE					
	0, A1		**SEC Action:** Continuation of project approved	Date		
	A2, B		**Considered by SEC below**	Date		
		2.3 Is any risk associated with access to project acceptable in context? If no, give reasons below:	Yes		No	
		3.1 Is involvement of human participants justified? If no, give reasons below:	Yes		No	
		3.3 Is experimental method acceptable with regard to risk and inconvenience to participants? If no, give reasons below:	Yes		No	
		4 Are arrangements for confidentiality and data protection appropriate? If no, give reasons below	Yes		No	

		5 Do arrangements for working with external bodies protect interests of participants and the external bodies? If no, give reasons below		Yes		No		
		SEC Action: Continuation of project approved:	Yes		No		Date	
		Conditions:						
	Other		**SEC Action:** Refer to University Ethics Committee				Date	

Guidelines

Section 1: Categorisation for ethical approval

Category 0: There are no third parties directly involved in the project and any artefacts produced by the project will not be accessible to a general audience.

Category A1

Projects involving human volunteers are involved solely for the purposes of:

- providing data to inform the specification of an artefact
- testing the usability or fitness for purpose of an artefact

where the nature of that artefact or its use will present no risk to the volunteers

and, if any artefact is accessible to a general audience, access to that artefact will present no risk.

Category A2

Projects involving human volunteers other than those defined in category A1 but not in activities defined in other categories or if any artefact is accessible to a general audience, access to that artefact may present some risk.

Category B

Projects involving human volunteers including potential risk, for instance, studies using new research methodologies, studies involving certain vulnerable populations or therapeutic interventions or other significant risk to anyone involved in the research (but not including trials of artefacts intended for therapeutic purposes).

Category C

Research being conducted by staff or postgraduate research students involving

Patients, clients staff, records etc. within the sphere of the NHS, Social Services, etc (but not including clinical trials of medicinal or related products).

Category D

Research being conducted by undergraduate or taught postgraduate students involving

Patients, clients staff, records etc. within the sphere of the NHS, Social Services, etc (but not including clinical trials of medicinal or related products).

Category E

Clinical trials of medicinal or related products involving patients or healthy volunteers as direct users of the product.

Question 2.2.1: You should answer yes if your artefact, product or information might be of direct risk or might lead or encourage people to alter their behaviour in a way which would be detrimental to them. Examples of direct potential risk might be a machine that could injure someone if it malfunctioned or a web resource which contained information which if it was misused would lead to risk (for instance, children's identities or addresses). Examples of artefacts which might encourage detrimental behaviour could be a web resource offering alternatives to expert (such as GP or lawyer) advice or products which purport to have a therapeutic effect.

Question 3.7.: As a general principle, all participants should be informed of their role in the experiment and freely consent (in writing) to it, which implies competence to give consent. Very occasionally it may be necessary to undertake an experiment without consent, or with participants who are not competent but then any decision about the acceptability of the proposal would be taken on the basis of the absolute benefit of the experiment in a wider context, and it would have to be established that there was no alternative.

Question 3.8: With regard to freedom of consent, it likely that this principle would be breached of the participants were subject to some kind of inducement or coercion, however minor. For instance, it is likely that participants who were under the management of the person undertaking the experiment would be considered to be under a degree of coercion.

Question 3.9: It may be considered that expecting a participant to spend undue time or effort participating in an experiment would be detrimental to the interests of that person, particularly where the results of the work offered no clear benefits. It may be appropriate to compensate participants for their time, but it is not acceptable to offer inducements to participate.

Section 4 Anonymity:

It is to be expected that due care and attention be paid to protecting information about individuals. Depending on the nature of the experiment, the following may be considered.

- Type 1: Complete anonymity of participants (i.e., You will not meet, or know the identity of participants, as they are part of a random sample and are required to return responses with no form of personal identification)?
- Type 2: Anonymised samples or data (i.e., an irreversible process whereby identifiers are removed from data and replaced by a code, with no record retained of how the code relates to the identifiers. It is then impossible to identify the individual to whom the sample of information relates)?
- Type 3: De-identified samples or data (i.e., a *reversible* process whereby identifiers are replaced by a code, to which you retain the key, in a secure location)?
- Type 4: Subjects being referred to by pseudonym in any publication arising from the project?
- Type 5: Any other method of protecting the privacy of participants? (eg. use of direct quotes with specific, written permission only; use of real name with specific, written permission only)